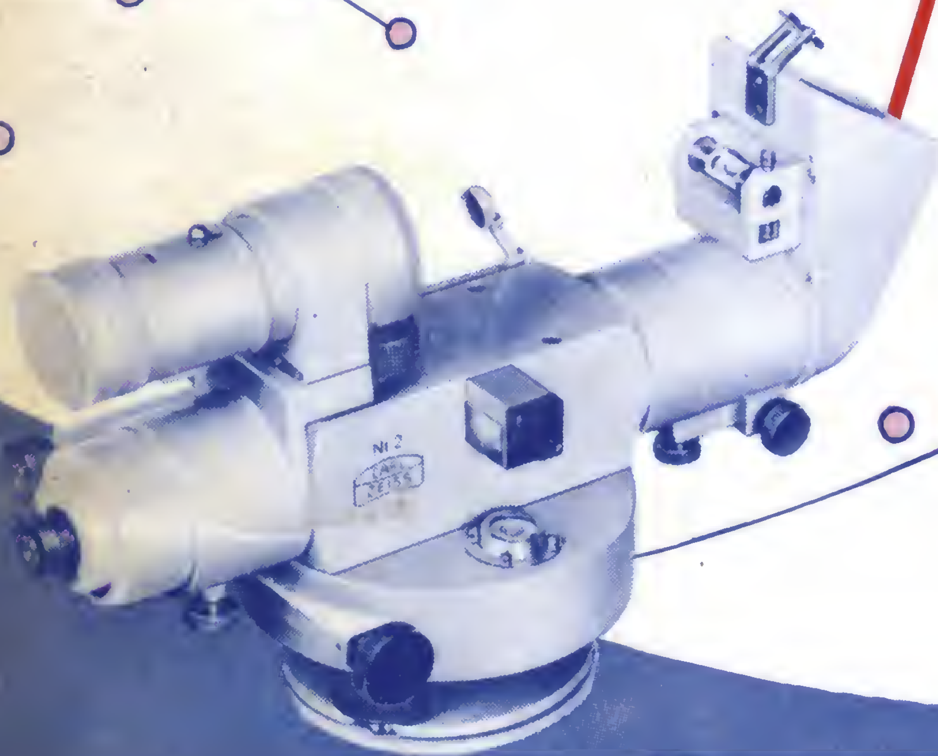
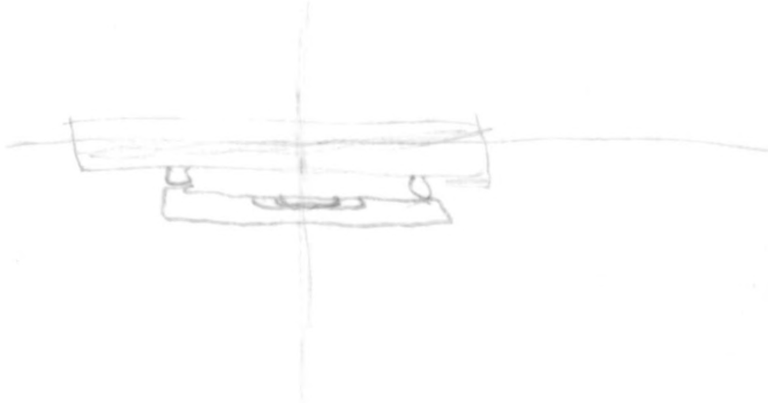
1963

SOLAR EPHEMERIS



and Surveying Instrument Manual

KEUFFEL & ESSER CO.



SOLAR EPHEMERIS for 1963

AND

SURVEYING INSTRUMENT MANUAL

KEUFFEL & ESSER CO.

NEW YORK HOBOKEN, N. J.

PHILADELPHIA DETROIT CHICAGO MILWAUKEE ST. LOUIS
DALLAS HOUSTON DENVER SAN FRANCISCO LOS ANGELES
SEATTLE ANCHORAGE TORONTO MONTREAL

1963 COVER. The illustration shows the Zeiss Ni 2 Self-Leveling Level (No. 75 0020) with Astrolabe attachment.

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K+E

SURVEYING INSTRUMENTS

K&E has been manufacturing Surveying Instruments since 1885. From the start, the company's policy has been to build only instruments of the highest quality. K&E has developed new materials, better methods of manufacture and radical improvements in design. To-day K&E's leadership is unquestioned.

The superb performance of K&E Surveying Instruments is recognized throughout the world. They are renowned for their fine workmanship, for the accurate results they produce and for the long years of service that they give. They need little attention, even under the most adverse field conditions.

Space does not permit an account of the many features that give these instruments their accuracy and long life, as for example the chrome plated center or the non-magnetic stainless steel trunnions, but several of their most outstanding features are described in the next paragraphs.

AUTOMATIC INDEXING

Automatic indexing is the most important recent development made in optical surveying instruments. It has increased considerably the speed and accuracy of operation. This feature is now incorporated in the following K&E instruments:

1. The Zeiss Self-Leveling Levels
2. K&E Theodolites, in which the index for zenith angles is set automatically
3. The Self-Indexing Plane Table Alidades
4. The Automatic Optical Plumb Bob

PRINCIPLES

In all automatic-indexing devices, optical parts, actuated by a pendulum, compensate for slight tilts in the main instrument. Since knife edges cannot be used to support the pendulum, as they would soon become dull, wires or membranes are substituted. These supports become stiffer in cold weather and more flexible in warm weather, and thus the compensation is too little or too great. However, when properly designed, the supports are relaxed when the instrument is level, so that temperature has a negligible effect on the slight movement of the pendulum. Temperature variation has little or no effect on the optical plumb bob.

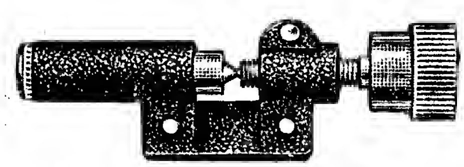
The plane of the pendulum swing must be parallel to the line of sight. If not, a slight error in leveling left and right will create an error in compensation. In an automatic level, if the circular bubble adjustment is slightly in error transversely and the telescope is always pointed in the same direction when set-up, the backsights will always contain a certain error, and the foresights the same error but of opposite sign. To avoid this accumulation of systematic error, the telescope should be pointed in alternate directions when leveled at successive set-ups. In K&E theodolites, taking the average zenith angle of a direct and reversed observation will eliminate this error. The error is too small to affect alidades and plumb bobs.

If an instrument is stored for a period of time or allowed to stand slightly out of level for thirty minutes or so, the pendulum support takes a slight temporary set which soon disappears as the instrument is used. This has very little affect when running levels if the foresights are taken immediately after the backsights. However, for the best results, the instrument should be leveled when stored or left standing on the tripod. This set has no effect on zenith

angles measured with a theodolite if direct and reversed observations are taken alternately and averaged. However, this makes it very difficult to adjust the zenith-angle index precisely, because the set changes during the time required for the adjustment. Therefore, zenith angles observed only once may be in error by as much as ± 8 seconds, i.e. about ± 0.02 feet in 500 feet. This set or hysteretic effect is too small to affect alidades or plumb bobs.

2-SPEED TANGENT SCREW

With an ordinary tangent screw, it takes a great deal of patience and skill to make the final pointing. Some even say that truly *exact* pointings are impossible. With the Two-Speed Tangent Screw, exact pointings and settings *can* be made *instantly*. Within the knurled head is a screw which acts against a stop pin on the inner drum. Normal motion is brought into action when the screw in the head is turned *against* the stop pin. When the head is turned in either direction free of the stop pin, a fine motion operates at a ratio of 8 to 1 as compared to the motion of the normal tangent screw thread. One knob controls both rough and fine adjustments, enabling rapid, one-hand operation, even with gloves on. Far greater accuracy and speed are possible than with any other setting and pointing mechanism.



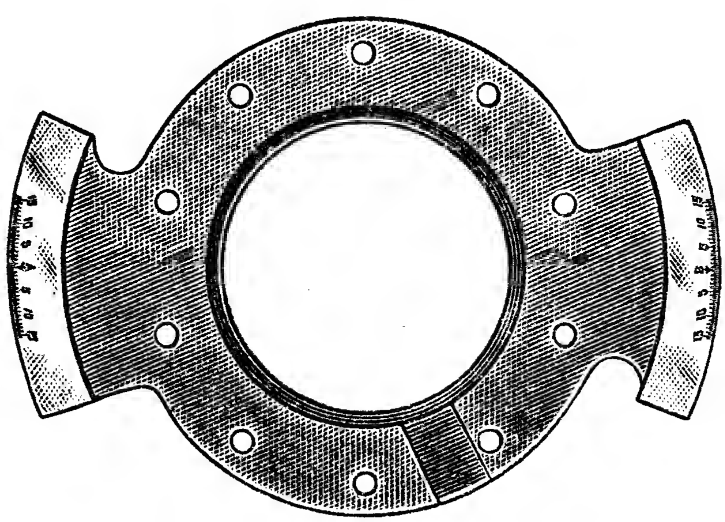
To bring the cross line on the mark or to set the vernier, turn the tangent screw in the direction required until the cross line or the vernier has moved just beyond the position desired. When the tangent screw is reversed to return to the mark, the low-speed ratio will function

for a short distance. Accordingly, low speed will operate across the mark and for a short distance each side of the mark. With this arrangement, the final precise setting is always made with the low speed ratio, no matter which way the screw is turned.

If you have a PARAGON Transit built since 1954, you can order these time-savers individually and install them yourself. Just unscrew the present tangent screw until it comes out and screw in the new one.

SPANNED VERNIERS

K&E now makes the two plate verniers as a single unit. This is a revolutionary development in transit design. It results in perfect verniers, perfectly positioned. Spanned verniers ensure precise alignment when assembled on the transit and eliminate the possibility that the verniers might be too "long or short." It follows that transits with spanned verniers are more accurate than similar instruments not so equipped. All K&E Transits, except the 74 0070, are now furnished with spanned verniers.



In this new development the A and B verniers are made integral parts of a plate or span. The

span is placed in the dividing engine and the verniers are graduated in a single operation. The procedure is identical to that used to divide the circle itself. The span is then mounted and centered on the transit exactly in the same way the circle is centered. Finally, the height of each vernier is set with two adjusting screws.

Without the span, verniers are clamped separately in a gang fixture to position them in the dividing engine. A speck of dirt might spoil their alignment. When they are assembled in the transit, they have to be carefully shimmed up until both ends of each vernier are level with the circle. Then each vernier has to be precisely positioned by actually shifting it until three different requirements are satisfied. These requirements are:

1. The two verniers must be set exactly 180° apart.

2. The two ends of each vernier must have the same clearance from the circle.

3. The clearance must have a specific value so that the readings they give will be correct. Needless to say, to make these adjustments by hand is a very difficult process.

Spanned verniers eliminate these difficulties. Once they are centered, the accuracy of the dividing engine is transferred to the verniers as well as to the circle.

OPTICAL SYSTEM

Keuffel & Esser Co. is a leader in the recent general advance in optical design. In every K&E telescopic instrument the field of view is exceptionally brilliant and free from color rings, the focus is sharp over the entire area of the

field, and the cross lines are exceptionally sharp and black.

These results have been attained by extremely careful optical design. Coated lenses are used throughout, except on the exterior surfaces where the coatings might be damaged.

Most transits today have a color-corrected objective lens. Very few have a color-corrected eyepiece. On the 74 0000 Transit, a new achromatic eyepiece makes the cross lines appear jet black.

With a K&E instrument it is possible to identify objects more readily, to sight points more precisely, to work more accurately in poor illumination, to read the stadia rod and the level rod at greater distances, and to observe Polaris earlier in the afternoon.

K&E THEODOLITES

The year 1960 marked the introduction by K&E of theodolites engineered specifically for American and Canadian practice. These Theodolites consist of three basic models, available with either erecting or inverting image, as follows:

Erecting Telescope

KE-2e 1 second, averaging

KE-1e 20 second, zero setting

KE-6e 1 minute, zero setting (Optical Transit)

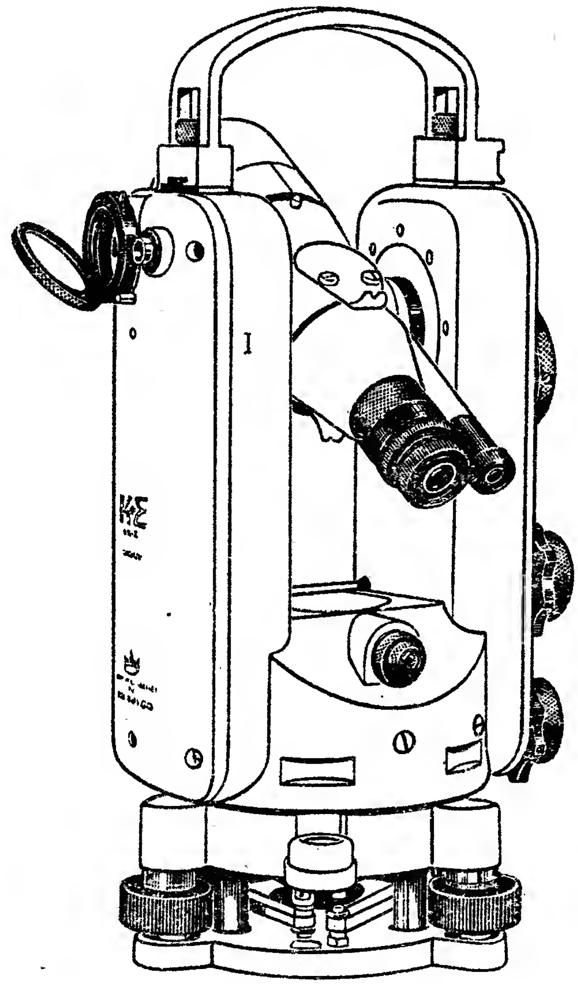
Inverting Telescope

KE-2 1 second, averaging

KE-1 20 second, zero setting

KE-6 1 minute, zero setting (Optical Transit)

The readings of each can easily be estimated to 1/10th of the value given above.



KE-2 Direction Theodolite—1 Second

The three basic theodolites are identical except for the optical-reading train and the zero setting (repetition) clamp.

These theodolites were designed and manufactured for K&E by the world famous Askania-Werke Corporation, known for their scientific instruments and well recognized in this country for their cinetheodolites. This company was selected after several years of investigation because of the superb design of their existing products and the exceptional continued high accuracy attained by their instruments under rigid testing.

These K&E theodolites are made to K&E

Specifications and Quality Standards, and are tested at the K&E facilities for complete conformity to these requirements. It is believed that each type will give results superior to any theodolite in its respective class.

FEATURES

The circles and micrometers are exceptionally accurate. The 30 power telescope has excellent definition and an unusually wide field of view (1° 30′). An exclusive linkage design connects the upper and lower plates of the leveling head, by a ball and socket joint arrangement, preventing any azimuth movement of the instrument base irrespective of any wear that may occur in the leveling screws.

The optical plummet is mounted on the alidade so that the accuracy of the set-up can be determined at any time by rotating the alidade 180°.

The vertical circle has a pendulum-actuated index which is considerably more sensitive than the plate level. This eliminates the need for a vertical index level and ensures accurate vertical angles especially when the average of direct and reverse readings is used. See Automatic Indexing, page 3.

The horizontal and vertical circles are viewed simultaneously. This eliminates the need for a selector knob and the possibility of taking the wrong reading because the knob was inadvertently turned the wrong way.

All internal parts are enclosed and completely sealed against dust. The instrument is a light Ivory Enamel color in order to reduce the effect of radiant heat.

The reticule has both vertical and horizontal

stadia lines set to a ratio of 1:100. No additive constant is required.

The alidade is attached to a special steel cylindrical spindle which is accurately fitted to its bushing. The weight of the spindle rests on ball bearings riding in a race between the shoulders of the spindle and its housing.

All controls necessary for pointing and reading, namely; clamps, tangent screws and micrometer knob, where applicable, are located on one side and operated by one hand. The coaxial double knobs are so designed that the larger star knobs actuate the clamps; the smaller knurled knobs, the slow motion screws. The relative position of the knobs is readily felt.

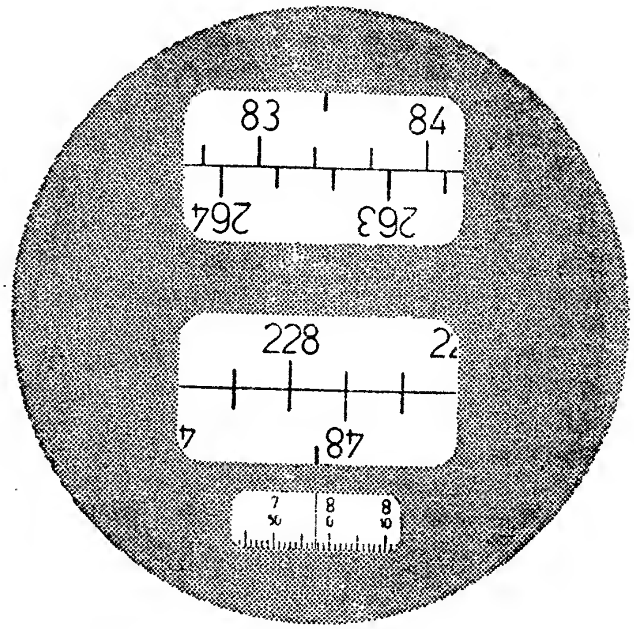
The tripod is of the same rigid design as other K&E wide frame tripods, having an extra-wide shifting center of 2 inches.

Night illumination can be provided by attaching a small lamp housing without moving any part of the instrument. The battery box, which hangs on the tripod, is plugged into the instrument base. Standard American flash light batteries are used.

Descriptive data pertaining to the three models is as follows.

KE-2 THEODOLITE

The circle reading system is designed so that the minutes and seconds obtained is the average of the readings of two opposite sides of the circle. Both circles of the KE-2 are read directly to one second by means of the micrometer scale, with estimation to 0.1 second. The circle orienting knob can be engaged only by moving a small lever and then pressing the knob. When released, the knob breaks contact and the lever locks in place serving as a safety catch.

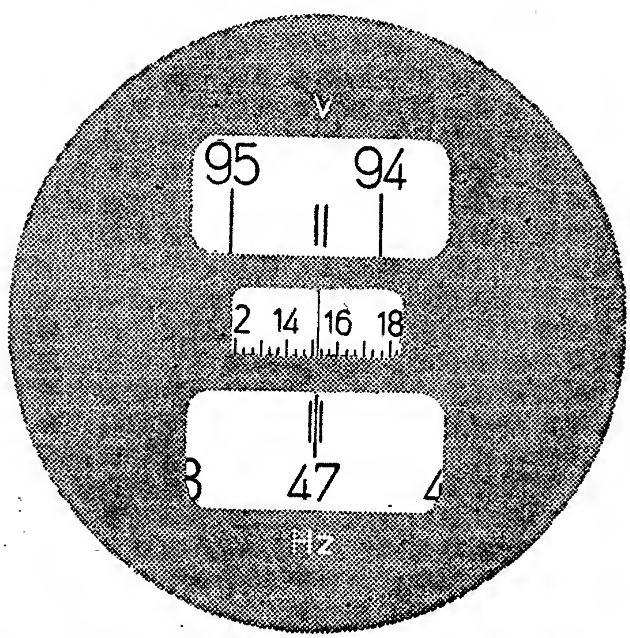


Horizontal reading—228° 17′ 57.6″

This instrument gives exceptionally rapid results on triangulation surveys and should be used whenever accuracy is paramount.

KE-1 THEODOLITE

Both circles of the KE-1 are read directly to twenty seconds by means of the micrometer scale, with estimation to 2 seconds.



Horizontal reading—47° 15′ 12″

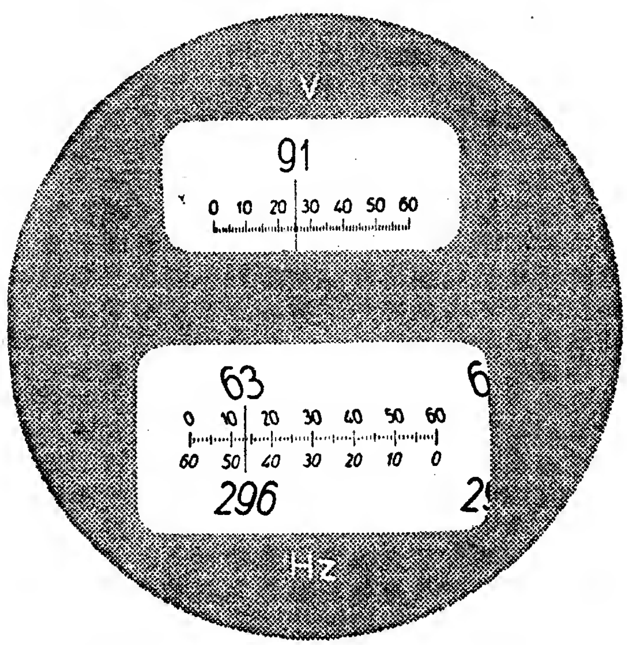
The theodolite has a repetition clamp so that it can be set to read zero and it can be used either as a direction or as a repeating instrument. Since any movement of the circle when clamping and unclamping will introduce error, the design of the K&E repetition clamp reduces this possibility to an absolute minimum.

The instrument is applicable for all surveys where lay-out work must be very accurate. It can be used equally well for triangulation, traverse and stadia surveys, making it an excellent high-grade general-use instrument.

KE-6e THEODOLITE

(Optical Transit)

Both circles are read simultaneously against a fixed scale without the necessity of a micrometer. Both circles can be read directly to 1 minute and estimated to 0.1 minute. The horizontal circle is graduated at every degree and numbered from 0° to 360° **both clockwise and counterclockwise.**



Vertical reading—91° 25.4′
Horizontal reading—clockwise—63° 13.6′ (upper row)
Horizontal reading—counterclockwise—296° 46.4′ (lower row)

The repetition clamp makes it possible to set it at zero or any desired angle and to use the KE-6e as a direction or a repeating instrument as required. It can be read or set quickly and definitely with assurance, and with considerably more accuracy than the best vernier-reading transit.

This instrument is especially useful for complicated lay-out work, like running curves or setting off unusual angles. It gives high accuracy in traverse or triangulation work and is especially fast in mapping. It should be used wherever faster, more accurate work is required than can be attained with an ordinary transit.

THEODOLITE ACCESSORIES

K&E has available a complete line of accessories that are fully interchangeable and designed to work with all K&E theodolites. For further information regarding K&E theodolites or accessories, write to Keuffel & Esser Co., Hoboken, New Jersey.

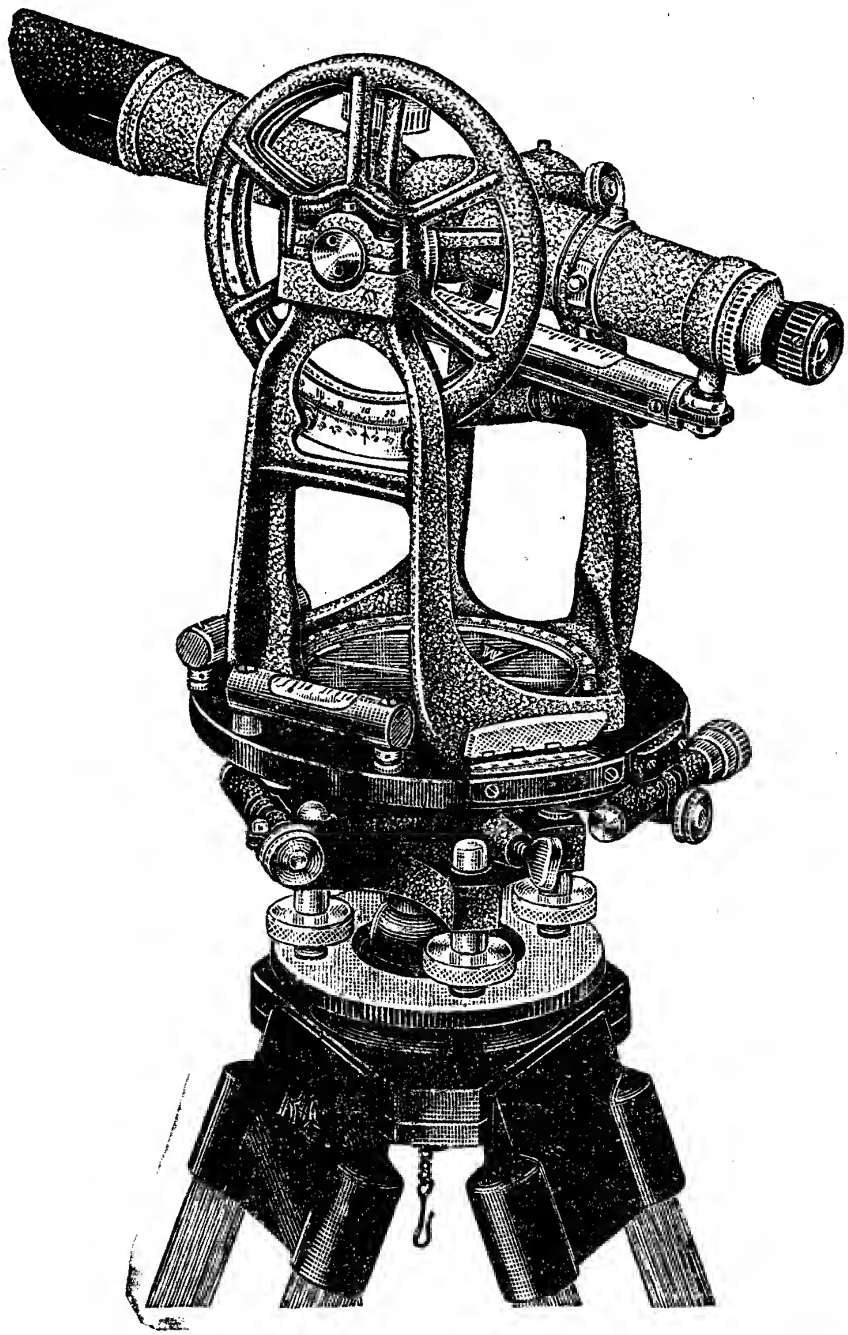
TRANSITS

The Repeating Transit. The repeating transit is a universal instrument of great versatility. It will perform every ordinary surveying operation required and, by proper operation, will give any desired accuracy.

Staking out Work. The instrument is excellent for setting out angles, straight lines, curves, and grades. The relatively long telescope and the erecting eyepiece make it easier for the transitman to bring the stakeman into the field of view and to give him the proper directions when his movements are observed through the telescope.

The double center makes it possible to set the vernier at zero (or at any required setting) before taking a backsight. This is an important

element in any layout work. Short lines of levels can be run and grades can be established well within the accuracies usually required, and high accuracy can be attained when desired by keeping the sights short.



K&E PARAGON® Transit 74 0000

Difficult Sighting Conditions. The fine optics of the K&E instrument make it espe-

cially useful for stadia work, Polaris observations and wherever the target is poorly illuminated.

Traverse Angles. By "repeating" angles in such a way that the sum of the measurements is accumulated on the circle, traverse angles can be measured as accurately as desired and with approximately the same speed as with a direction theodolite.

Triangulation. The angles of a triangulation system can also be measured as accurately as desired with a repeating transit, but the many repetitions required take longer than measurements of the same accuracy made with a direction theodolite.

Essential Design. A repeating transit consists of three major assemblies: the alidade, the circle assembly and the leveling head. Because of its double center, the alidade turns within the circle and the circle within the leveling head.

Principle of the Clamps

On the circle assembly, immediately below the circle itself, are two collars, which serve as brake drums for the upper and lower clamps. When the upper clamp is tightened, the circle is clamped to the alidade. When the lower clamp is tightened, the circle is clamped to the leveling head, hence to the ground. After either clamp has been tightened, a precise setting between the two parts clamped together can be made with the appropriate tangent screw.

To measure an angle, both clamps should be loosened, then the zero of the vernier on the alidade is brought to the zero of the circle, the upper clamp is tightened and a precise setting is made with the upper tangent screw. The telescope is then directed toward the first point, the lower clamp is tightened and the cross lines are brought exactly on the point with the lower tangent screw. The line of sight will now be exactly on the first point and the vernier will be at exactly zero.

The upper clamp is loosened and the telescope is directed toward the second point, thus moving the vernier around the circle. The upper clamp is then tightened and the cross lines are brought exactly on the second point with the upper tangent screw. The vernier will then give the exact value of the horizontal angle.

With this as a beginning, the reader is referred to the many excellent textbooks available.

THE USE OF TRANSITS

While every transitman is familiar with the operation of a transit, certain important points in using the instrument, which make for better results, are outlined here.

To Tighten the Tripod Shoes. It is essential that the tripod shoes be kept tight. On a conventional tripod, if the shoes are loose, tighten the wood screws that hold them to the tripod legs. If this fails, remove the shoes and refit the ends of the tripod legs. On a K&E Wide Frame Tripod, the shoes practically never become loose. They may be tightened with the hexagonal headed bolt found on the opposite side of the shoe from the spur.

To Adjust the Tripod Hinges. If the tripod hinges are too loose, there will be play that may destroy the accuracy of the work. If they are too tight, residual friction may suddenly give way and the instrument will move slightly off line, without the knowledge of the transitman.

On a conventional tripod, each of the wing nuts should be just tight enough to allow the leg to fall *slowly* by its own weight. On a K&E Wide Frame Tripod, the hinges hardly ever require adjustment. Occasionally they should be oiled and wiped dry. The hinge friction adjusting nuts are located under the corners of the tripod head. They should be adjusted so that the leg will fall *freely*, but still develop a

slight friction that can be felt when the legs are moved by hand.

To Mount the Transit. Set up the tripod with the legs well spread, the feet set firmly into the ground and with the head nearly level. Unscrew the tripod cap.

Place the transit case on a flat surface, open the door, grasp the leveling head and carefully slide out the instrument on its base plate. Take off the objective cap and replace it with the sunshade. (The sunshade should always be used, as it reduces glare, never cuts off any useful light, and gives the telescope a more nearly even balance.)

Grasp the instrument with both hands at the leveling head, unscrew it from the base plate and screw it firmly home on the tripod head. Open the eyepiece shutter by moving the small pin into its slot.

To Focus the Telescope. Unless the eyepiece is focused accurately for the observer's eyesight, and the objective is also accurately focused, parallax may impair the accuracy of the work.

Point the telescope at a bright, unmarked surface or at the sky, and rotate the eyepiece focusing ring until the cross lines appear at their maximum sharpness. Next sight the telescope at some well defined point and bring the object into sharp focus by means of the objective focusing pinion. Move the eye left and right or up and down and observe whether the cross lines remain on the point sighted. If they appear to move, adjust the focus by rotating the eyepiece focusing ring back and forth while making small adjustments with the objective focusing pinion until all apparent motion is eliminated.

To Level the Instrument. Always begin the process of leveling the instrument by loosening *two adjacent* leveling screws. Level the instrument by adjusting two pairs of opposite

leveling screws alternately, keeping the pressure on the tripod plate very light until the instrument is practically level. Finish by slightly increasing the pressure until the screws are firm but not tight. If one pair of screws should bind, loosen *one* screw of the *opposite pair*.

To Level the Instrument with the Telescope Level. When sights are taken to objects at a considerable vertical angle above or below the instrument, the accuracy of the results depends to a large degree on how accurately the instrument has been leveled. No system of observations will eliminate errors of leveling. It is a good rule to level the instrument with the telescope level when sights with a vertical angle of over 20 degrees are to be observed.

Level the instrument in the usual manner. Turn the vertical circle vernier to zero, set the upper clamp and turn the instrument until the telescope is aligned with a pair of opposite leveling screws. Set the lower clamp. Center the telescope bubble with the vertical tangent screw. Free the upper clamp and turn the instrument 180°. If the telescope bubble does not center, bring it half way toward the center with the vertical tangent screw. Level again with the leveling screws and repeat until the telescope bubble will center in both positions. Turn the instrument 90° and level with the leveling screws. The telescope bubble should now remain centered when the telescope is pointed in any direction.

Avoid any Contact with the Instrument. While operating the instrument never allow the clothing to come in contact with the tripod or the instrument. Never touch the instrument itself, except at the points necessary for operation, and when completing a sight be sure to touch only the tangent screw involved.

Reading the Vernier. To read the vernier hold the reading glass at least 1½ inches above the window. Steady the hand by touching the

upper plate with the little finger. Keep both the center of the glass and the eye exactly in line with the lines on the part of the vernier that is being observed.

Raise the Compass Needle. Never pick up the instrument without raising the compass needle from its pivot. The least jar will cause the hard jewel to break off the fine pivot point, and thus make the needle sluggish. The needle will never be accurate again until the pivot has been resharpened.

To Use the Stadia Circle. Some transits are equipped with the K&E Stadia Circle No. 74 0505. The use of these circles facilitates stadia surveying by eliminating measurement of the vertical angle and the use of tables. For more detailed description of stadia surveying see page 104.

To Use the Base Plate for a Trivet. Three sharp pointed threaded studs are packed in each instrument box. When they are screwed into the bottom of the base plate it becomes a trivet. It can be used instead of a tripod for set-ups on wood or masonry or for very low set-ups.

To Return the Instrument to its Case. Be sure that the leveling head is near the center of the tripod plate. Level the instrument so that the leveling head is parallel to the tripod plate. Clamp the telescope securely so that it is approximately horizontal. Tighten the upper clamp securely and free the lower clamp. Unscrew the instrument from the tripod and screw it securely on the base plate. Turn the telescope so that it faces left and is parallel to the long edge of the base plate. Tighten the lower clamp securely. Loosen the leveling screws slightly, so that the instrument will shift.

Slide the base plate under the guides in the bottom of the case. If there is a chocking block at the back of the case, shift the instrument

as it moves in, so that it is centered in the block. If there is no block in the case, center the instrument carefully. Push the base home and tighten two adjacent leveling screws securely.

Make sure that the telescope is free from all contact with the case and that the leveling screws and the clamps are all tight. See that the door closes without interference. Do not force the door. If it will not close without strain, something is wrong. Finally close the door and fasten the hooks. Replace the tripod cap and strap the tripod legs.

To Transport the Instrument. Keep it from vibration and away from contact with any hard surface. On the floor of a car, stand the case on its rubber feet. Place some soft material around it to prevent it from falling. Before shipping instruments see page 95.

TRANSIT CARE

Rain, Snow or Dust. Rain or snow will not damage the instrument. If it becomes wet, let the instrument dry off, if possible in some dust-free place. It is not necessary to wipe it off. Excess dust penetrating an instrument will damage it. It is for this reason that K&E instruments are made virtually dustproof and moistureproof. If it is necessary to work in dust or in rain, keep the waterproof hood over the instrument as much as possible.

To Clean the Lenses. Considerable dirt can accumulate on the objective lens (front lens) without affecting the operation of the instrument. If the light through the telescope appears to be dim, it is probably caused by dirt on the exterior surface of the rear eyepiece lens rather than on the objective. To reach this surface remove the eyepiece end cap. To clean the lenses work off the dust with the camel hair brush provided. It is almost never

necessary to remove the objective lens from a K&E telescope. This operation should be performed only by a competent instrument repairman. Even loosening and reseating the lens will disturb adjustments 4, 6, and 7 (pages 34-37) and, unless the lens is removed in dry, dust-free air, the telescope may be damaged.

To Avoid Damage. The instrument should never receive a blow of any kind. If it should fall over, a factory repair will usually be required. It is advisable to follow these two well known rules:

1. Never leave the instrument unattended when it is out of its case.

2. Never set up the instrument without finding good footing for the tripod and spreading the legs wide.

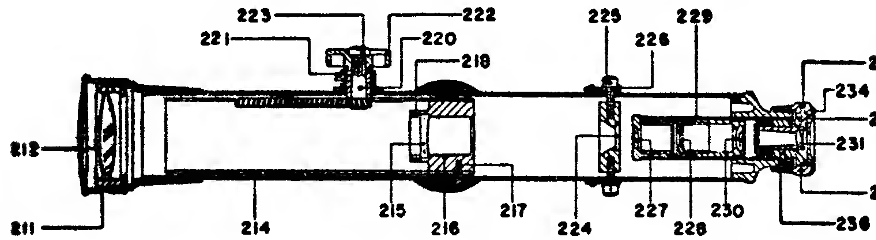
DIAGRAMS AND COMPONENT PARTS OF K+E TRANSITS

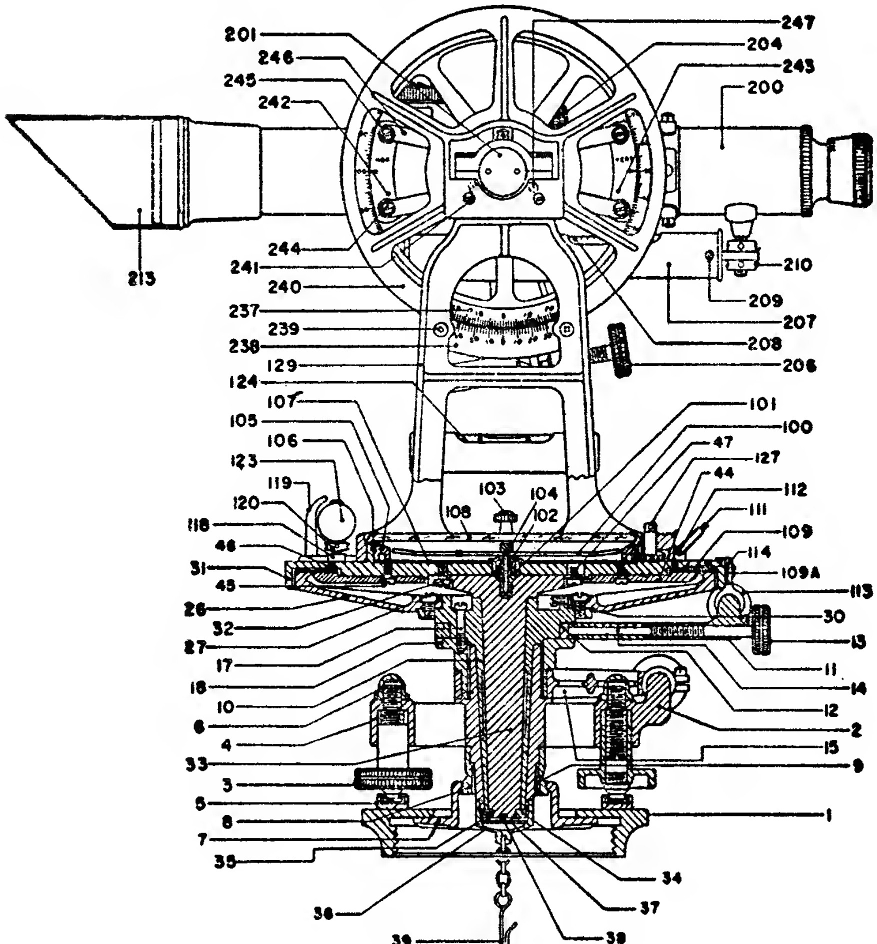
The subnumbers listed on the following pages refer to the same numbers on the diagrams.

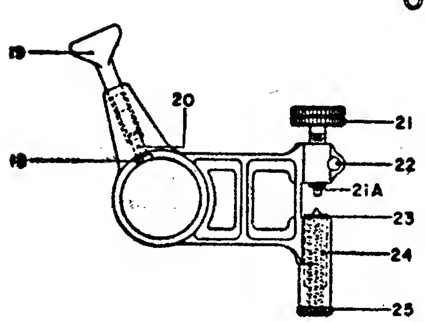
When ordering repair parts always give the serial number of the instrument and, if possible, the catalog number also.

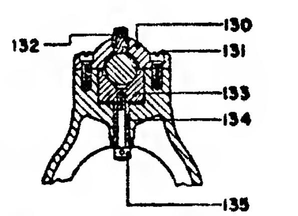
K&E PARAGON® TRANSITS

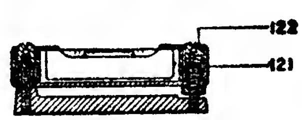
"U" STANDARD











"U" STANDARD

5205-1 Tripod Plate
2 Leveling Head
3 " Screw Head
4 " " Stem
5 " " Shoe
6 " " Cap (Left Hand Thread)
7 Shifting Plate
8 Half Ball
9 " " Lock Screw
10 Outer Center
11 Vernier Plate Clamp
12 " " " Gib
13 Vern. Pl. Cl. Screw
14 Vernier Plate Clamp Screw Pin
15 Lower Clamp
16 " " Collar
17 " " " Mounting Screw
18 Lower Clamp Gib
19 " " Screw
20 " " Screw Pin
21 Lower Clamp Tangent Screw
21A Clamp Tangent Screw Pivot Pin
22 Clamp Tangent Screw Tension Screw
23 Lower Clamp Tangent Screw Plunger
24 Lower Clamp Tangent Screw Spring
25 Lower Clamp Tangent Screw Cap
26 Horizontal Circle
27 " " Mounting Screw
30 Horizontal Circle Adjusting Screw
31 Vernier Plate
32 " " Mounting Screw
33 Inner Center
34 Center Nut
35 " " Lock Screw
36 Center Cap
37 " Spring
38 " Ball
39 Plumb Bob Chain and Hook
44 Spanned Verniers
45 " " Mounting Screw
46 Spanned Verniers Height Adjusting Screw
47 Spanned Verniers Centering Screw
100 Compass Needle
101 " " Lifter
102 Compass Needle Lifter Bushing
103 Compass Needle Lifter Screw Assembly
104 Compass Needle Pivot
105 " Ring
106 " " Spring
107 " Dial
108 " Cover Glass & Mount
109 Vernier Cover Glass
109A Vernier Cover Glass Strap
109B Vernier Cover Glass Strap Screw (not shown)
111 Vernier Reflector
112 " " Frame & Hinge
113 Vernier Plate Clamp Tangent Screw
114 Vernier Plate Clamp Tangent Screw Spring Box
115 Tang. Sc. Plunger †
116 " " Spring †
117 " " Cap †

†(Not shown but similar to Nos. 22, 23, 24 & 25.)
†(For Vernier Plate & Telescope Cl. Tang. Screws)

118 Plate Level Bracket & Posts complete
119 Plate Level Vial Guard
120 Plate & Standard Level Adj. Nut
121 Plate & Standard Level Spring
122 Plate & Standard Level Post Cap
123 Plate & Standard Level Vial, Tube & Ends complete
124 Plate & Standard Level Vial

When ordering parts, state Serial No. of instrument

K&E PARAGON® TRANSITS

"U" STANDARD

5205-125 Standard Level Post, Fixed †
126 Standard Level Post, Adjustable †
127 Declination Adjustment Pinion & Washer
129 Standard
130 Trunnion Cap
131 " " Screw
132 " Friction Screw
133 Trunnion Bearing Block
134 Trunnion Bearing Block Adjusting Screw
135 Trunnion Bearing Block Lock Screw
200 Telescope Barrel & Axle
201 Tele. Axle End Cap
202 Telescope Clamp (Not shown)
203 Telescope Clamp Gib (Not shown)
204 Tele. Clamp Screw
205 Telescope Clamp Screw Pin (Not shown)
206 Telescope Clamp Tangent Screw
207 Tele. Level Vial, Tube & Ends complete
208 Tele. Level Vial only
209 Telescope Level Tube End Lock Screw
210 Telescope Level Adjusting Nut
211 Objective Cap
212 " Lens & Mount
213 Sunshade
214 Telescope Draw Tube
215 " Focusing Lens
216 Telescope Focusing Lens Mount
217 Telescope Focusing Lens Mount Lock Screw
218 Telescope Focusing Lens Lock Ring
219 Telescope Focusing Pinion, Pinion Head (222) & Screw (223) complete
220 Telescope Focusing Pinion
221 Telescope Focusing Pinion Lock Screw
222 Telescope Focusing Pinion Head
223 Telescope Focusing Pinion Head Screw
224 Reticule
225 Reticule Adjusting Screw
226 Reticule Adjusting Screw Shutter
227* Eyepiece Lens I & Mount
228* Eyepiece Lens II & Mount
229* Eyepiece Tube
230* Eyepiece Lens III & Mount
231* Eyepiece Focusing Lens & Mount
232* Eyepiece Focusing Ring
233* Eyepiece Focusing Ring Set Screw
234* Eyepiece Cap
235* " Focusing Sleeve
236* Eyepiece Focusing Sleeve Screw
237 Vertical (Stadia) Circle
238 Vertical Circle Vernier
239 " " " Post & Nuts
240 Vertical Circle Guard
241 " " " Screw
242 Stadia Index, Horizontal
243 Stadia Index, Vertical
244 Stadia Index Lock Screw
245 Stadia Index Adjusting Screw
246 Stadia Index Frame
247 " " " Screw

†Not shown

*Nos. 227 to 236 apply to Achromatic Eyepiece only.

When ordering parts, state Serial No. of instrument.

MAINTENANCE, LUBRICATION AND DISASSEMBLY OF TRANSITS

Precautions for Taking the Instrument Apart. *In general, the instrument should never be taken apart.* If it becomes absolutely necessary to take it apart for lubrication, this should be done indoors and where there is no dust. The greatest care should be exercised throughout the entire operation as *there is more chance for damage and for the infiltration of dust when the instrument is taken apart than in many years of field service.*

Transits must be lubricated only very occasionally. Only special instrument lubricant should be used. Very little should be applied, as excess lubricant collects dust. Each surface to be lubricated should be wiped dry with a clean lint-free cloth. If the surface is gummy, a little naphtha may be used to clean it. Interior surfaces can be reached by covering a wooden stick with the cloth. Lubricant equivalent to not more than one drop of fine watch oil should be applied at each of the points listed. The lubricant should be applied to each part just before re-assembly. It should be well spread and worked in and then all excess carefully wiped dry. To work the lubricant into the center bearings, put the two mating parts together, then raise and turn and lower to four or five positions.

PARTS TO BE LUBRICATED

1. Bearing surface and shoulder of inner center.

2. Outer bearing surface and shoulder of outer center.

3. Telescope axle bearings.

4. Spring and plunger for each tangent screw.

5. Threads of clamp screws, tangent screws and leveling screws.

6. Collars and surfaces of the three clamps.

7. Surface of half ball and both surfaces and thread of tripod plate.

To reach some of these points the transit must be partly disassembled. The steps for taking it apart and reassembling it are given here.

TO DISASSEMBLE THE TRANSIT

1. Turn the telescope horizontal, tighten all three clamps, and unscrew and remove the three tangent screws. Note where each belongs.

2. Unscrew and remove the three tangent screw spring box caps together with their springs and plungers. Note where each belongs.

3. Remove the vertical circle guard fastening screws and remove the guard, taking great care not to touch the vertical circle.

4. Remove the telescope trunnion cap screws and lift the trunnion caps off.

5. Lift out the telescope. Unscrew the telescope clamp lock nut. Unscrew the telescope clamp screw and take off the clamp, being very careful not to touch the vertical circle. Lay the telescope assembly down without allowing the vertical circle to touch anything.

6. Lay the instrument carefully on its side and unscrew the plumb bob chain and eye or center cap 36, if provided. Be careful not to drop out the ball 38 and spring 37.

7. Loosen the center nut lock screw, if one is provided. Remove the center nut 34 with the special wrench provided.

8. While pushing the leveling head and the standards together, carefully set the instrument

upright. Lift out the alidade carefully, rotating it back and forth slightly to start it. Avoid touching the center bearing surfaces with the end of the center. Lay the alidade carefully on its side with the center horizontal but not touching anything. Lift out the circle assembly with the same care, being sure to avoid touching the circle graduations with the fingers. Lay it face down on a clean, soft cloth.

9. Loosen the leveling screws. Turn the leveling head on its side and remove the half ball lock screw 9 and unscrew the half ball 8. The shifting plate and the tripod plate will come off with it.

10. If the instrument has fully enclosed leveling screws, unscrew the leveling screw caps. (These are left hand threads.) Unscrew the four leveling screws. Note where each belongs. Unscrew the leveling screw stems. Thread and unscrew the leveling screw shoes.

If the instrument has exposed leveling screws, remove the leveling screw dust caps if any. Unscrew the leveling screws. Note where each belongs. Thread and unscrew the leveling screw shoes if the instrument has this type.

11. Loosen the lower clamp screw and remove the assembly. Note which side is uppermost.

12. Unscrew the upper clamp collar screws. These are the slotted screws, and they are nearest the center. (On some instruments these are on the lower side of the collar.) Mark the position of the collar with a pencil. Be very careful not to touch the circle centering screws or vernier disc centering screws. If these are disturbed, the centering of the circle and vernier disc will be lost. Re-centering is impossible except by a trained instrument repairman. Remove the collar. Loosen the upper clamp

and remove it. The gib and the connecting shaft can be dropped out.

13. Remove both upper and lower clamp screws.

All surfaces that need to be cleaned and oiled are now exposed.

TO RE-ASSEMBLE THE TRANSIT

1. Replace the upper clamp screw, the connecting shaft and the gib. Replace the assembly on the drum with the lug up. Replace the upper clamp collar and screws and screw them home, with equal pressure on each. Tighten the clamp.

2. Replace the lower clamp screw, replace the assembly, and tighten the clamp.

3. Replace the leveling screw assembly. Make sure the stems are tight and the leveling screws are screwed well in (on instruments with fully enclosed leveling screws).

4. Place the tripod plate and the shifting plate in position and screw on the half ball. Turn the half ball home so that the lock screw can be replaced, and screw in the lock screw.

5. Stand the leveling head upright, tighten the leveling screws so that the head is about parallel with the tripod plate and not free to tilt. Lower the circle assembly carefully into place. Avoid touching the bearing surface or the shoulder with the end of the center. While the circle assembly is being lowered, turn it so that the lower clamp fits over the lug on the leveling head.

6. Carefully lower the alidade into place. Avoid touching the bearing surface or the shoulder with the end of the center, or the circle with the vernier plate. While the alidade is being lowered, turn it so that the lug on the clamp fits between the two parts of the spring

box. When it has been lowered almost home, see that the circle assembly still rotates freely and be careful to avoid striking the verniers against the edge of the graduated circle.

7. While pushing the leveling head and the standards together, turn the instrument on its side and replace the center nut. Screw it home. Tighten the lock screw, if provided. Replace the center nut cap, if provided. Then stand the instrument erect.

8. Replace the telescope clamp and the telescope clamp lock nut. Place the telescope axle in its bearings.

9. Replace the telescope trunnion caps according to the matching numbers. Be sure that the bearing surface of the friction screw is aligned with the axle. Replace the screws and screw them home.

10. Replace the tangent screw plungers, springs, caps and tangent screws.

11. Replace the vertical circle guard.

12. Adjust the friction screw at the top of the left hand telescope axle trunnion cap so that the telescope is free, but will not move from its own weight with the sunshade in position and the instrument focused at a distant point.

To Remove the Reticule. If it is necessary to remove the reticule, proceed as follows:

1. Loosen the set screw at the eye end of the main telescope tube and unscrew the eyepiece.*

2. Remove the two horizontal reticule adjusting screws. Loosen the top adjusting screw and, by turning both top and bottom screws, turn

*On some instruments it is first necessary to remove the four eyepiece centering ring screws.

the reticule so that its plane is parallel with the telescope.

3. Thread a pointed stick of soft wood into the side screw hole of the reticule now facing the eyepiece end of the telescope.

4. Remove the two remaining reticule adjusting screws and carefully withdraw the stick with the reticule on it.

If the reticule has spider web cross lines, the spider web can be removed with alcohol.† New spider web should be replaced under tension and placed exactly on the scribed marks on the reticule. This should be done under plenty of light and using the eyepiece as a microscope. The new spider web can be held in place with a drop of shellac.

To replace the reticule in the telescope reverse the order of the steps for removing it.

After replacement, the stadia ratio should be re-determined.

CAUTION

After the instrument is completely re-assembled, all adjustments should be tested.

Preparation for Arctic Temperatures. A K&E repeating transit will operate perfectly at Arctic temperatures if lubricated with special cold temperature lubricant. This can be purchased through any K&E dealer or branch. The instrument should be disassembled and all the old lubricant removed with naphtha before applying the special lubricant.

ADJUSTMENTS

Surveying instruments should be tested frequently but adjusted rarely. Modern instruments seldom get out of adjustment. Adjustments are sometimes necessary after repairs, but the chief need for adjustment is caused by improper adjustments that were not required in the first place.

†This operation should be attempted only if it is impossible to obtain the services of a skilled instrument repairman.

Before it is assumed that adjustments are necessary, it is essential to be positive that any apparent lack of adjustment is actually due to the condition of the instrument and is not caused by deficiencies in the test. To test an instrument properly, observe the following precautions:

1. If possible, choose a cloudy day.

2. See that the tripod shoes are tight and the instrument firmly screwed to the tripod.

3. Set up on firm ground, out of the sun but in good light, where clear sights of about 200 ft. can be made in opposite directions.

4. Spread the tripod feet well apart and place them so that the tripod plate is nearly level. Press the shoes firmly into the ground or place them in chipped depressions in masonry.

5. If a conventional tripod is being used, after setting up, free and then tighten all three tripod hinge screws to relieve residual friction. With a K&E Wide Frame Tripod, this operation is unnecessary.

6. Attach the sunshade and carefully focus the eyepiece. After leveling the instrument, loosen all four leveling screws slightly and relevel to relieve any residual strain. Have all screws equally firm but not too tight. Too much force will deform the centers and introduce both friction and play.

7. Go through all of the tests in the order given for the type of instrument being tested. Do not adjust the instrument unless a particular test indicates the *same* amount of error at least three times.

Be on the lookout for *creep*, particularly when adjusting the levels. Creep is caused by tripod settlement, or by the temperature of the instrument changing. This is particularly apt to happen if the instrument has just been brought out-of-doors or is exposed to body or other

radiant heat. After setting a bubble or the line of sight, let it stand a few seconds to see that no movement occurs.

8. Before making the adjustment, consider whether or not the error discovered will have a material effect on field results. In making this decision remember that most tests make the error appear double in amount.

Adjustments should be made in the order given, so that no previous adjustments will be disturbed. At the completion of the adjustment the parts should be set firmly home without strain. After any adjustment has been made, the proper test should be applied at once. After all the contemplated adjustments have been completed, all of the tests should be applied again in the proper order, in case some other adjustments might have been disturbed.

TRANSIT ADJUSTMENTS

First read the general directions under "Adjustments" on pages 31-33.

Plate Levels

1. ***Object***. To adjust the plate levels so that the bubbles will center when the azimuth axis of the instrument is placed in the direction of gravity, i.e. made truly vertical.

Test. Set the horizontal circle vernier at zero. Clamp the upper clamp. With the lower clamp free, turn the instrument in azimuth until each plate level is aligned with a pair of opposite leveling screws. Set the lower clamp. Center the bubbles precisely. Free the upper clamp and turn the instrument 180° in azimuth. The bubbles should center.

Adjustment. If either bubble fails to center, bring it half way back with the leveling screws. Then, by turning the capstan head nut at the adjustable end, raise or lower that end of the level tube until the bubble centers.

The Cross Line Reticule

2. ***Object.*** To center the cross lines on the optical axis. This adjustment should not be made if it can be avoided, as it needs to be only approximately correct and it disturbs three other adjustments.

Test. If the cross lines appear to be in the center of the field of view they are near enough to the optical axis to give good results.

Adjustment. The cross line reticule is held in position by the four capstan head reticule adjusting screws in tension. Loosen two adjacent screws. By adjusting the four screws with the fingers, center the cross lines. Tighten the screws by alternately turning a vertical screw and a horizontal screw by small increments.

3. ***Object.*** To rotate the reticule until the vertical cross line is in a plane perpendicular to the elevation axis.

Test. Aim at a sharply defined point. Move the line of sight up and down with the telescope tangent screw. The vertical cross line should remain on the point.

Adjustment. Loosen two adjacent reticule adjusting screws. Gently tap the sides of the screws so that they move around the telescope until the vertical cross line is rotated to its correct position. Tighten the same screws. As the cross lines are placed on the reticule at right angles at the factory, when the vertical line is correct, the horizontal line is also in its correct position.

4. ***Object.*** To make the line of sight perpendicular to the elevation axis.

Test. Sight some well defined point 200 feet or more distant. Reverse the telescope on its elevation axis and note or mark a point appearing on the vertical cross line at about the same

elevation and distance from the instrument as the first point, but in the opposite direction. By turning the instrument approximately 180° in azimuth, again sight the original point. Again reverse the telescope on its elevation axis. The vertical cross line should fall on the second point.

Adjustment. Loosen the top reticule adjusting screw. Then by loosening one side screw and tightening the other alternately by small increments, move the cross line one quarter the distance toward the second point. Tighten the top screw. Recheck adjustments 2 and 3.

The Elevation Axis

5. ***Object.*** To make the elevation axis perpendicular to the azimuth axis.

Test. Sight some elevated point, such as a church steeple. Depress the telescope and note or mark a point near the ground on the vertical cross line. Reverse the telescope and turn it approximately 180° in azimuth. Sight the lower point. Raise the telescope. The vertical line should fall on the upper point.

Adjustment. Move the cross line between one quarter and half the distance toward the upper point by raising or lowering the movable bearing block in one of the standards.

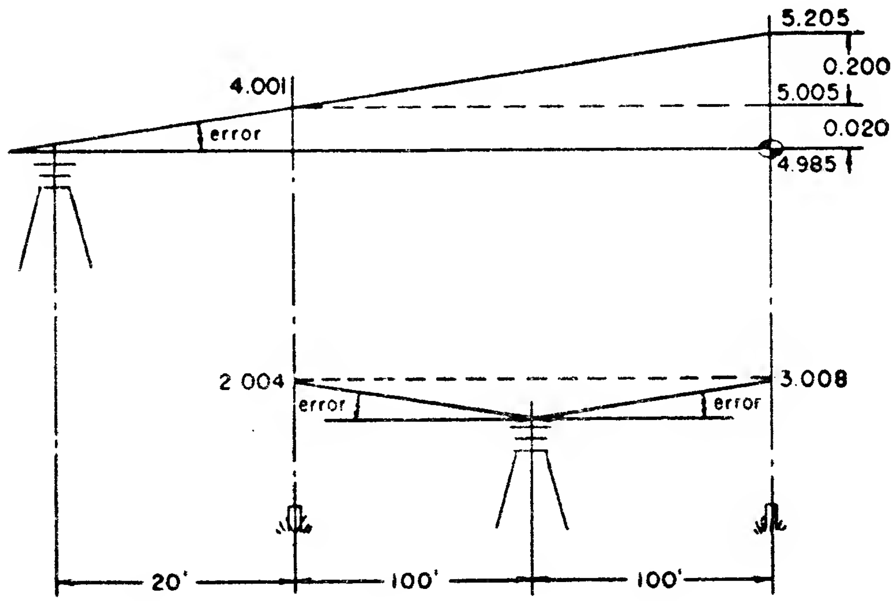
The Telescope Level

6. ***Object.*** To make the telescope level center when the line of sight is horizontal.

Test. The test is made by the *peg* method.

On fairly level ground set up the instrument where it is protected from the direct rays of the sun, and drive two stakes in opposite directions at exactly equal distances from the instrument. Preferably the stakes should be about 100 feet from the instrument. Take a rod reading on each stake. Level the telescope carefully for each reading, using the telescope level. The dif-

ference between the two readings will be the true difference in elevation between the stakes. Then set up in line with the two stakes, but at a known distance beyond one of them equal to some convenient decimal fraction of the distance between the stakes. Level the telescope carefully, and take a reading on the near stake.



The figure illustrates the operation described. If the reading of the near stake is 4.001, the reading on the far stake should be 4.001 plus the difference between the values obtained at the center set up, i.e. 3.008 − 2.004 = 1.004. 4.001 + 1.004 = 5.005. Assume that the horizontal cross line strikes at 5.205. The line of sight must slope upward at a rate of 0.200 ft. in 200 ft. In the 20 ft. between the instrument and the near stake, the error introduced by this slope is, by similar triangles, 1/10 of 0.200 ft. or 0.020 ft. Applying the two errors to the reading of the far stake, 5.205 − 0.200 − 0.020 = 4.985. A target set at 4.985 will be level with the instrument.

If the line of sight, instead of striking above the computed reading, strikes below it, the two errors must be added to the rod reading instead of being subtracted from it.

Set the target accordingly. Using the vertical tangent screw, bring the horizontal cross line to the target.

Adjustment. Center the telescope level by raising or lowering the adjustable end by means of the adjusting nuts.

The Vertical Circle Vernier and Stadia Indices

7. ***Object.*** To make the vertical circle vernier read zero, the horizontal stadia index read 100, and the vertical stadia index read 50,* when the line of sight is perpendicular to the azimuth axis.

Test. Level the instrument with the telescope level as described on page 19. The vernier and the two stadia indices should give the proper readings.

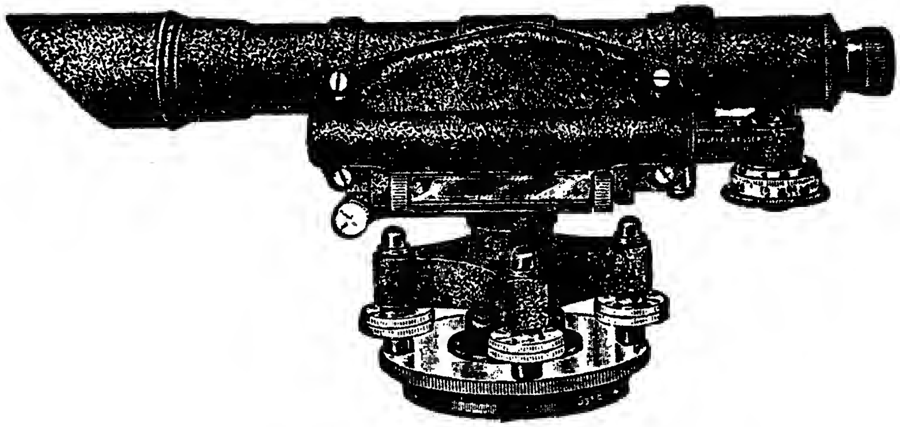
Adjustment. Loosen the screws slightly that hold the parts to be adjusted and tap them until the correct reading is obtained. Tighten the screws. Make sure that the vernier or the indices have not been set so close to the circle that they bind.

LEVELS

In addition to the transit, K&E offers three types of leveling instruments. The distinctive qualities of these instruments are described in the following pages.

The Tilting Level (K&E 75 0000). This instrument is designed for precision and speed. It has an erecting telescope of about 30 power. The bubble is observed through a coincidence device from a position about one inch to the left of the eyepiece. The bubble is centered by turning a micrometer screw, placed directly

*Omit references to stadia indices if the instrument is not so equipped.



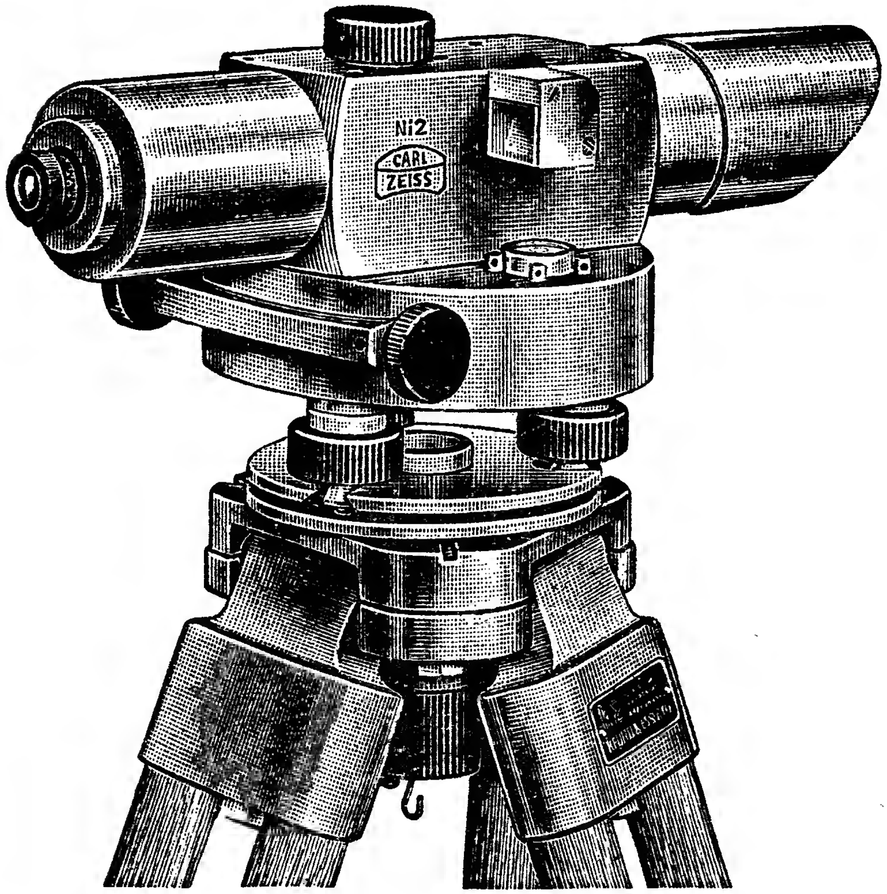
K&E PARAGON® Tilting Level 75 0000

below the eyepiece end of the telescope, until the two ends of the bubble appear to coincide. This gives an extremely accurate setting and makes it possible to read the rod and to check the bubble almost simultaneously.

When the instrument is first set up, the leveling head is leveled roughly with the small circular bubble, which may be observed in a mirror from a point about one inch to the right of the eyepiece. No time is wasted in walking around the instrument, or in turning it in azimuth, or by unnecessary precision in leveling it.

Adjustment is checked by means of the peg test. Any adjustment necessary is accomplished by moving the coincidence assembly backward or forward with a single screw. The instrument is recommended for all leveling work where speed with accuracy is essential.

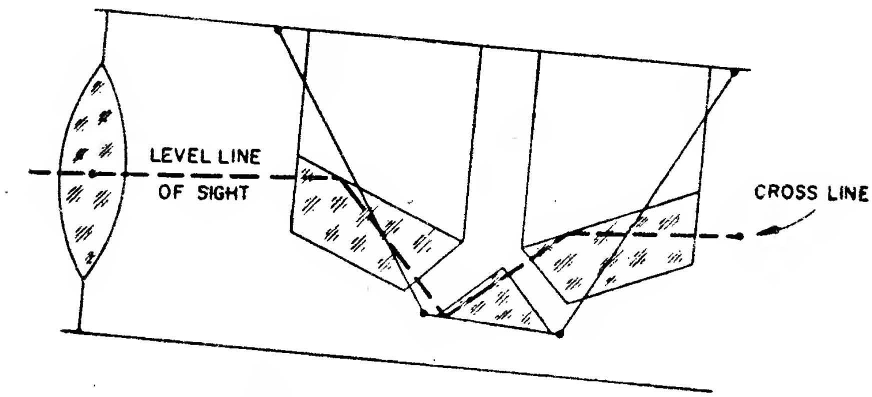
The Zeiss Self-Leveling Level (K&E 75 0020). This level is an unparalleled instrument. When it has been leveled by centering the circular level, it holds the line of sight precisely level *automatically*. It has been known to give first-order accuracy and is very fast and simple to use. These qualities make it an all-



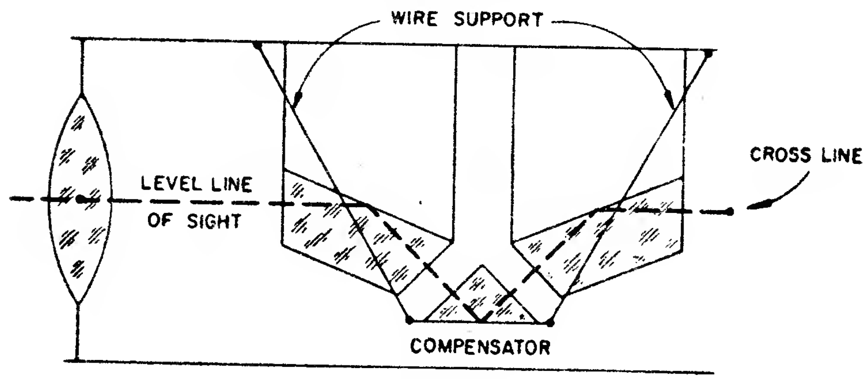
Zeiss Self-Leveling Level (K&E 75 0020)

purpose level, which can be used with great advantage for any type of work from cross-sectioning to benchmark leveling. It is faster and more accurate than any of the instruments usually employed.

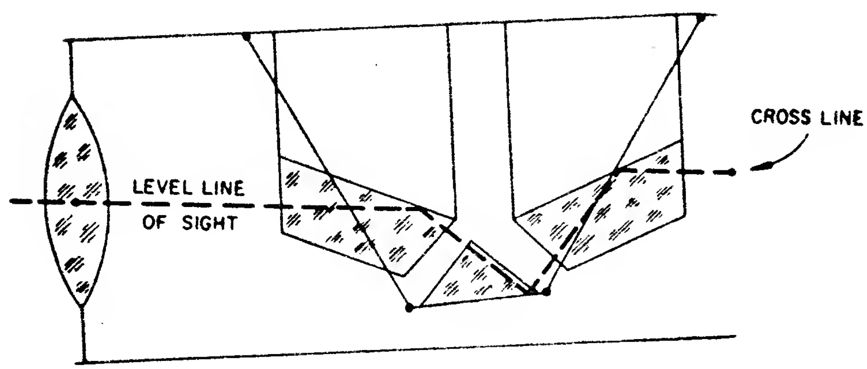
The schematic line drawing (page 40) shows how it works. When the telescope is tilted, a prism called the *compensator* swings to a position that levels the line of sight. The movement of the prism is air-damped by a disk-like cylinder which moves over a stationary piston (not shown).



WHEN TELESCOPE TILTS UP
COMPENSATOR SWINGS BACKWARD



TELESCOPE HORIZONTAL



WHEN TELESCOPE TILTS DOWN
COMPENSATOR SWINGS FORWARD

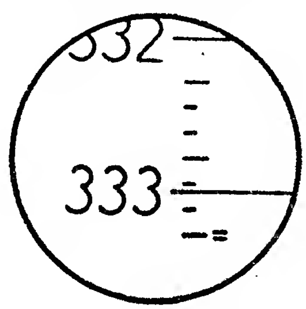
The three leveling screws have a fast pitch for rapid, approximate leveling. There is no azimuth clamp. The azimuth movement of the upper part of the instrument is controlled by an *adjustable brake*. The exact azimuth desired is

set with an endless tangent screw, with two thumb screws, for either hand. The stiffness of the screw can be regulated by turning one thumb screw against the other. The focusing device has a high and low gear. A continuous motion in one direction utilizes the high gear. When the motion is reversed, the low gear operates for a short distance for precise focusing.

The reticule has stub stadia lines placed to give a stadia ratio of 0.3 : 100 for three-wire leveling. Other ratios* are available to order. The minimum focus is 11 feet. A focus reducing lens No. 75 0210 is available, which, when attached, reduces the minimum focus to 5.9 feet.

An Observation Prism makes it possible to view the circular level horizontally, so that the advantages of setting up at eye height can be utilized.

The Zeiss Self-Leveling Level with an Azimuth Circle (K&E 75 0030). The instrument described in the preceding section is also made with an azimuth circle. The circle is read through an auxiliary telescope to the left of

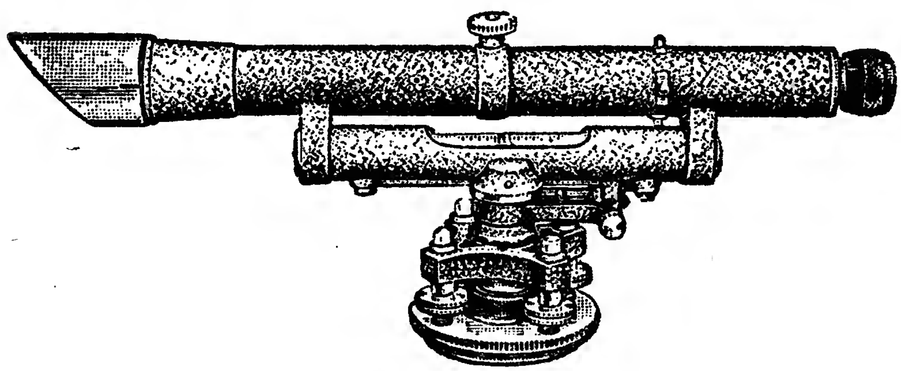


the main telescope. The line drawing shows what appears in the field of view. As the telescope is turned clockwise, the numbered degree graduations move downward. The number of minutes that any degree graduation has moved beyond the "0" mark is estimated on the stationary scale as shown. The reading is 333° 17′.

It can be used for small stadia surveys and for setting off angles for building construction.

* Other ratios, 0.6:100 and 1:100.

It has proved to be especially useful for aligning cross sections at exactly right angles to the centerline. In level country the rod can be aligned, the reading taken, and the offset distance determined by stadia in one operation. Spot elevations and topographical details can be located from the centerline by angle and stadia when a transit is not available and, in general, many operations can be carried out for which a transit is usually required.



K&E PARAGON® Dumpy Level 75 0300.

The Dumpy Level (*K&E 75 0300*). This is designed for accuracy, reliability and permanence of adjustment, and low cost. It contains a minimum number of parts. It is recommended for high grade leveling when fast operation is not a controlling factor.

The Transit. This can also be used as a level with excellent results. However, it is difficult to see the bubble through the standards and the speed of operation is accordingly reduced. But for general all-around surveying utility, of course, the transit is unsurpassed.

THE USE OF LEVELING INSTRUMENTS

THE TILTING LEVEL

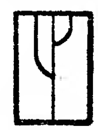
If the optimum performance of the Tilting Level is desired, the proper procedure for first order leveling and the "least squares" method of adjusting the results should be followed. For

these the reader is referred to Special Publications Nos. 239 and 240 of the U.S. Department of Commerce, Coast and Geodetic Survey, *Manual of Geodetic Leveling* and *Manual of Leveling Computation and Adjustment* by Howard S. Rappleye.

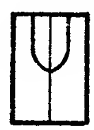
To Take a Rod Reading center the circular bubble with the leveling screws. This is a very quick operation, as it is unnecessary to turn the instrument in azimuth and the low sensitivity of the circular bubble prevents waste of time by too precise leveling at this stage.

Focus the telescope on the rod.

In the mirror or in the oblong window to the left of the telescope the bubble ends may be seen

something like  or perhaps like 

Turn the screw until the bubble ends are in

coincidence like this: 

The line of sight is now horizontal.

Take the rod reading.

Check the bubble coincidence immediately.

If the bubble ends coincided both ***before*** and ***after*** the observation, they must have coincided ***during*** the observation.

If the bubble ends are not bright, turn the reflector under the bubble so that more light is reflected up through the bubble tube. If the bubble ends do not appear, turn the micrometer screw until they come into view.

In extremes of temperature, the point of coincidence will appear near the top or the bottom of the window, according to the actual length of the bubble. This, of course, does not affect the accuracy of the instrument.

For Faster Rough Leveling. Profile leveling, cross sectioning and other rough leveling can be speeded up by use of the reversing point. The reversing point is the position of the tilting screw operating wheel that causes the bubble to center when the vertical axis is vertical. When the wheel is in this position, the instrument can be precisely leveled with the leveling screws exactly like a dumpy level. Once it is leveled in this manner, cross-section shots can be safely taken to hundredths of a foot without releveling.

Set up the instrument, center the circular bubble, turn the telescope until it is in line with a pair of opposite leveling screws, and center the main bubble with the tilting wheel by observing the coincidence of its ends. Turn the telescope 180° in azimuth and center the bubble by moving it half the distance with the leveling screws and half the distance with the wheel. Turn the telescope 90° in azimuth and center the bubble with the leveling screws. Repeat this procedure until the bubble ends remain in an 1/8 inch of coincidence in all positions. The tilting wheel will now be at its reversing point. Mark this position with a pencil or note the reading of the graduated circle if the instrument is so equipped.

The reversing point should be checked from time to time as it will change as wear occurs in the instrument.

When the circular level is in good adjustment, cross-section shots up to 200 feet long can be safely taken to tenths of a foot when the instrument is leveled with the circular level alone. Set the tilting wheel at its reversing point and center the circular bubble. Less than 10% of the shots will be in error by more than 0.05 foot.

ZEISS SELF-LEVELING LEVEL

Open the case, remove the instrument and place it on the tripod. The hold-down screw, attached to the tripod, is threaded into the hole

at the base of the instrument. Tighten the screw firmly.

There is a very important rule that must be followed. *Always keep the circular level in perfect adjustment* as described under adjustment of levels on page 57. Neglect of this rule may cause the compensator to stick or to give inaccurate readings. The instrument should always be leveled so that the bubble is near the center of the vial. In precise leveling operations it must be centered *accurately*. When it is centered, the movement of the compensator is at a minimum. As the compensator is especially accurate near the center of its movement, this improves the accuracy of the work.

When very accurate results are required, the telescope should be pointed backward while the instrument is being leveled at the first instrument position, forward while being leveled at the second instrument position, and so on alternately throughout the level run. This eliminates the accumulation of certain, very small systematic errors. See section on Automatic Indexing, page 3.

Never relevel after the first sight has been taken. Unlike a 4-screw leveling head, the movement of any screw in a 3-screw leveling head changes the height of the instrument.

Be very careful when using the instrument on bituminous surfaces or on frozen ground. Unlike conventional spirit levels, it gives no indication of settlement by going out of level. Thus, changes in the height of instrument may go unnoticed.

THE DUMPY LEVEL

The Dumpy Level operation is well known. Certain important points in using any type of leveling instrument that make for better results are outlined here.

(1) ***Operations like those of a Transit.*** The following operations are accomplished in

the same manner as described for transits on pages 17-19, 21:

1. To tighten the tripod shoes.
2. To adjust the tripod hinges.
3. To focus the eyepiece.
4. To level the instrument.
5. To avoid contact with the instrument.
6. To transport the instrument.

(2) ***Make sure the Bubble is Centered.*** The telescope should be aimed at, and focused on the rod before the bubble is precisely centered. The moment it is centered, the rod should be read and the bubble checked immediately afterward. When this procedure is followed the bubble is sure to be exactly centered at the moment the rod is read.

(3) ***Balance the Sights.*** At any instrument position the backsight, to obtain the height of instrument, and the foresight, to carry the elevation forward, should have nearly equal horizontal lengths in order to neutralize any residual error in instrument adjustment.

(4) ***Establish Benchmarks by Using them for Turning Points.*** Never establish the elevation of a benchmark by a single foresight. Instead, make it part of the level line by using it as a turning point. Then when the line of levels checks on a previously established benchmark, the shots to the new benchmark are automatically checked.

(5) ***Mark all Turning Points before Using them.*** If a turning point is not marked when the foresight is taken on it, some other point might be used in error for the next backsight.

CARE OF LEVELING INSTRUMENTS

Same as for Transits (pages 21-22).

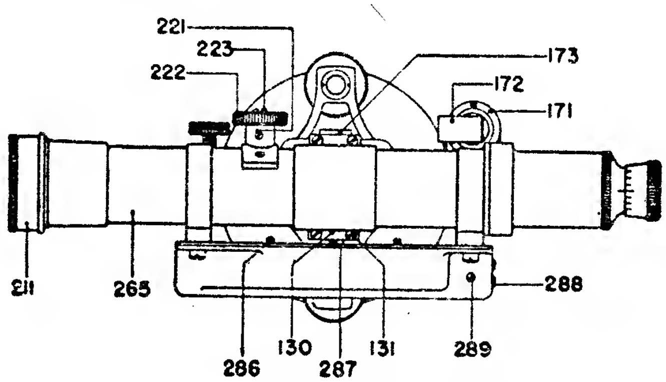
DIAGRAMS AND COMPONENT PARTS OF K+E LEVELS

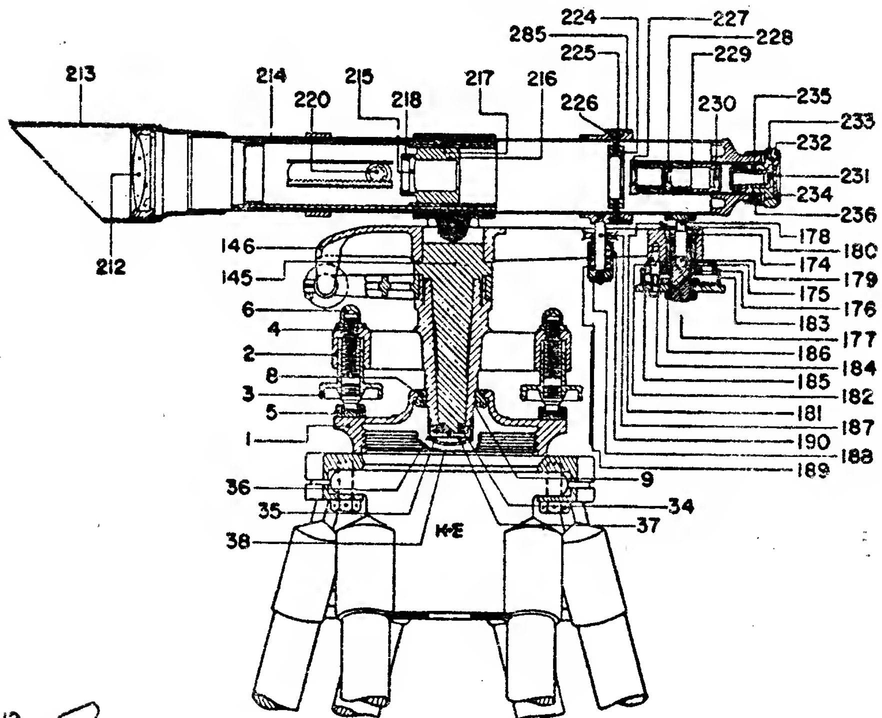
The subnumbers listed on the following pages refer to the same numbers on the diagrams.

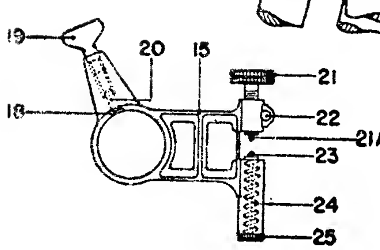
When ordering repair parts always give the serial number of the instrument and, if possible, the catalog number also.

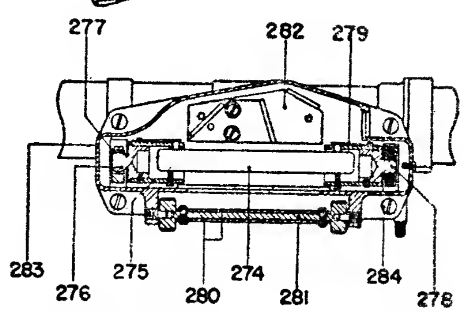
K&E PARAGON®

TILTING LEVEL







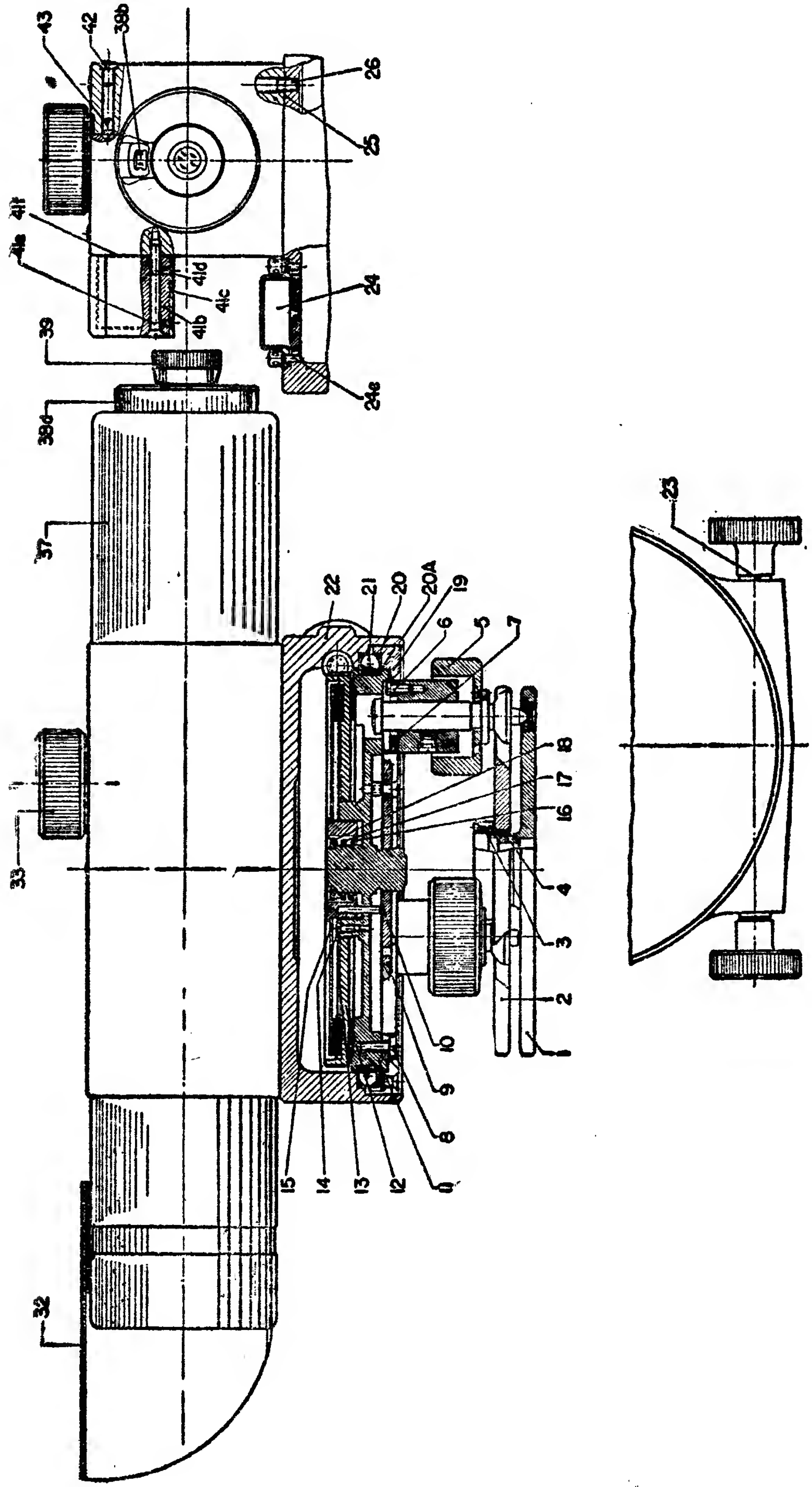


5210-1	Tripod Plate	15	Clamp
2	Leveling Head	18	" Gib
3	" Screw Head	19	" Screw
4	" " Stem	20	" " Pin
5	" " Shoe	21	" Tangent Screw
6	" " Cap	21A	" " " Pivot Pin
8	Half Ball		
9	" " Lock Screw		

5210-22 Clamp Tangent Screw Tension Screw
23 Clamp Tangent Screw Plunger
24 Clamp Tangent Screw Spring
25 Clamp Tangent Screw Cap
34 Center Nut
35 " " Lock Screw
36 Center Cap
37 " Spring
38 " Ball
130 Trunnion Cap
131 " " Screw
145 Center
146 Level Bar
171 Circular Level
172 " " Reflector
173 Telescope Trunnion Rosette
174 Tilting Screw Bushing
175 Tilt. Sc. Index Drum
176 Tilt. Sc. Bushing Lock Nut
177 Tilting Screw
178 Tilt. Sc. Pivot
179 " " " Ball
180 " " " Guide Plate
181 Tilt. Sc. Pivot Guide Pl. Screw
182 Tilt. Sc. Scale Drum Stop Screw (Fixed)
183 Tilt. Sc. Scale Drum
184 Tilt. Sc. Scale Dr. Stop Screw
185 Tilt. Sc. Knob
186 " " " Lock Nut
187 Tilt. Sc. Tension Stud
188 Tilt. Sc. Tension Stud Lock Nut
189 Tilt. Sc. Tension Spring
190 Tilt. Sc. Tension Spring Housing
211 Objective Cap
212 " Lens & Mount
213 Sunshade
214 Tele. Draw Tube
215 Telescope Focusing Lens
216 Telescope Focusing Lens Mount
217 Tele. Focusing Lens Mount Lock Screw
218 Tele. Focusing Lens Mount Lock Ring
219 Telescope Focusing Pinion, Pinion Head (222) & Screw (223), complete
220 Tele. Focusing Pinion
221 Telescope Focusing Pinion Lock Screw
222 Telescope Focusing Pinion Head
223 Telescope Focusing Pinion Head Screw
224 Reticule
225 " Adj. Screw
226 Reticule Adjusting Screw Shutter
227 Eyepiece Lens I & Mount
228 Eyepiece Lens II & Mount
229 Eyepiece Tube
230 " Lens III & Mount
231 Eyepiece Focusing Lens & Mount
232 Eyepiece Foc. Ring
233 Eyepiece Focusing Ring Set Screw
234 Eyepiece Cap
235 " Focusing Sleeve
236 Eyepiece Focusing Sleeve Screw
265 Telescope Barrel
274 Level Vial
275 " " Tube
276 " " " Ball End
277 Level Vial Tube Ball End Tension Spring
278 Level Vial Tube Adjustable End
279 Level Vial Tension Spring
280 Level Vial Light Reflector
281 Level Vial Light Reflector Holder
282 Level Viewing Unit
283 " Vial Housing
284 " Vial Housing Screw
285 Reticule Adj. Sc. Cover
286 Bubble Adj. Lock Scr.
287 " " Screw
288 Mirror Attach. Screw
289 Screw for Bubble Adjusting Hole

When ordering parts, state Serial No. of instrument.

ZEISS Ni 2
SELF-LEVELING LEVEL



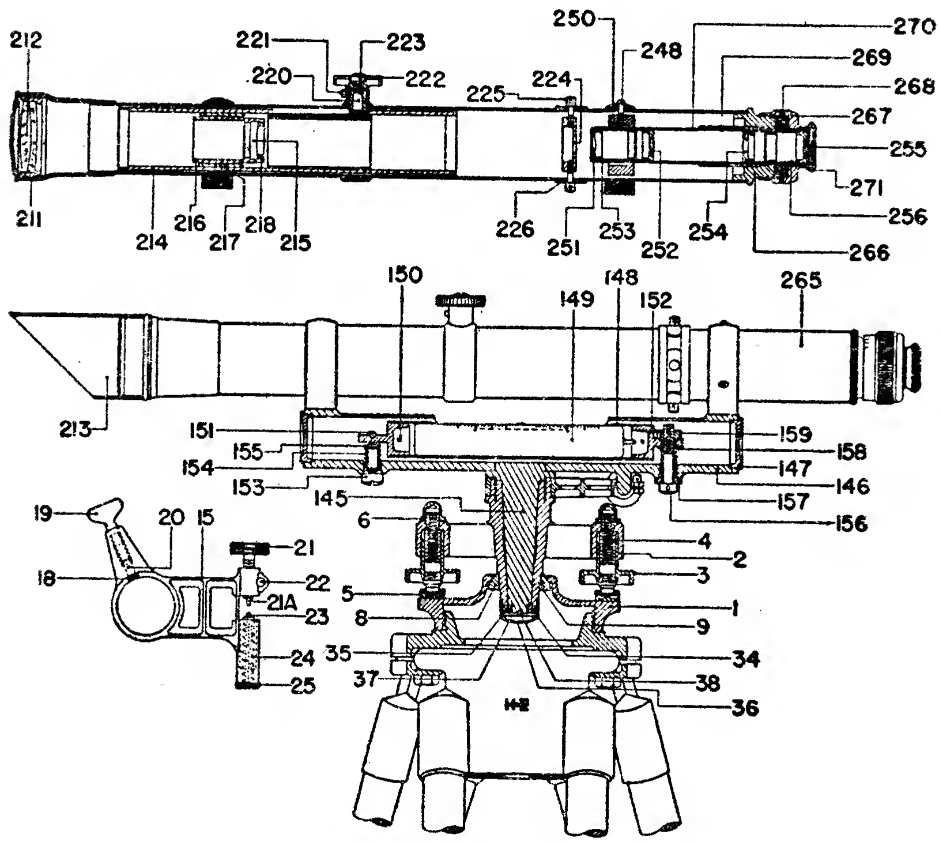
ZEISS Ni 2
SELF-LEVELING LEVEL

5223-1 Lower Foot Plate
2 Upper Foot Plate
3 Tension Spring
4 Foot Plate Lock Ring
5 Leveling Screw, Complete Assembly
6 Leveling Screw Assembly Fastening Screw
7 Leveling Screw Mounting Ring
8 Mounting Ring Screw
9 Friction Adjusting Disk with Stop Screw
10 Membrane
11 Lower Friction Plate with Cork
12 Worm Gear Plate
13 Membrane
14 Membrane Mounting Screw
15 Membrane with Cork Surface
16 Set Spring Housing
17 Set Spring
18 Set Spring Lock Ring
19 Ball Cage with Shoe & Lock Screw
20 Ball Race, Outer Ring
20a Ball Race, Inner Ring
21 Ball (Mention Quantity Required When Ordering)
22 Box Housing for Telescope
23 Lateral Drive, Complete Assembly
24 Circular Vial & Housing, Complete Assembly
24c Adjusting Screw
25 Telescope Supporting Disk
26 Telescope Housing Mounting Screw
32 Sunshade
33 Telescope Focusing Pinion, Complete Assembly
37 Ocular, Complete Assembly
38b Reticule Adjusting Screw
38d Reticule Screw Cover
39 Eyepiece Cap with Diopter Scale
41b Mount
41c Lock Plate
41d Prism Plate Screw
41e Observation Prism Assembly Mounting Screw
41f Intermediate Disk
42 Cover Screw
43 Focusing Pinion Lock Screw

When ordering parts, state Serial No. of instrument.

K&E PARAGON®

DUMPY LEVEL



5215-1 Tripod Plate
2 Leveling Head
3 " Screw Head
4 " " Stem
5 " " Shoe
6 " " Cap
8 Half Ball
9 " " Lock Screw
15 Clamp
18 " Gib
19 " Screw
20 " " Pin
21 " Tangent Screw
21A " Tangent Screw Pivot Pin
22 " Tangent Screw Tension Screw
23 " Tangent Screw Plunger
24 " Tangent Screw Spring
25 " Tangent Screw Cap
34 Center Nut
35 Center Nut Lock Screw
36 Center Cap
37 " Spring
38 " Ball
145 Center
146 Level Bar
147 " " End Cap
148 Telescope Level Vial Tube & Ends complete
149 Telescope Level Vial only
150 Telescope Level Tube End Lock Screw
151 Telescope Level Pivot
152 " " Tube End Position Pin
153 Telescope Level Tension Screw
154 Telescope Level Tension Screw Spring
155 Telescope Level Tension Screw Stud

K&E PARAGON®

DUMPY LEVEL

5215-156 Telescope Level Adjusting Screw
157 Telescope Level Adjusting Screw Bushing
158 Telescope Level Adj. Sc. Washer
159 Telescope Level Adjusting Screw Nut
211 Objective Cap
212 " Lens & Mount
213 Sunshade
214 Telescope Draw Tube
215 " Focusing Lens
216 Telescope Focusing Lens Mount
217 Telescope Focusing Lens Mount Lock Screw
218 Tele. Focusing Lens Mount Lock Ring
219 Telescope Focusing Pinion, Pinion Head (222) and Screw (223) complete
220 Telescope Focusing Pinion
221 Telescope Focusing Pinion Lock Screw
222 Telescope Focusing Pinion Head
223 Telescope Focusing Pinion Head Screw
224 Reticule
225 " Adjusting Screw
226 Reticule Adjusting Screw Shutter
248 Eyepiece Centering Screw
250 Eyepiece Centering Ring
251 Eyepiece Lens I & Mount
252 Eyepiece Lens II & Mount
253 Eyepiece Draw for Nos. I & II
254 Eyepiece Lens III & Mount
255 Eyepiece Lens IV & Mount
256 Eyepiece Draw for Nos. III & IV
265 Telescope Barrel
266 Eyepiece Body
267 " Focusing Ring
268 Eyepiece Focusing Ring Screw
269 Eyepiece Cam Screw
270 " Draw Tube
271 " Cap

When ordering parts, state Serial No. of instrument.

MAINTENANCE, LUBRICATION AND DISASSEMBLY OF LEVELING INSTRUMENTS

(Except the Zeiss Self-Leveling Level)

In the maintenance of levels, the following are accomplished as described for transits on pages 26, 27, 30, 31.

1. Precautions for taking the instrument apart.
2. To remove the reticule.
3. Preparation for Arctic temperatures.

A level is lubricated in the same manner as a transit (see page 26), except that only the following points need be lubricated:

1. Bearing surface and shoulder of center.
2. Spring and plunger of clamp.
3. Threads of clamp screw, tangent screw and leveling screws.
4. Collar and surface of clamp.
5. Surface of half ball, and upper surface and thread of tripod plate.

If the level is a tilting instrument the following points should also be lubricated:

1. Micrometer screw.
2. Telescope trunnion bearings.
3. Tilting screw compression spring.

TO DISASSEMBLE THE LEVEL

If the level is a tilting instrument, first remove the telescope from the trunnion bearings as follows:

1. Unscrew tension stud lock nut (188) and tension spring housing (190). The tension spring should fall out.

2. Unscrew telescope trunnion bearing cap screws (131) and remove caps (130), noting matching numbers.

3. Lift out telescope.

4. Then proceed as for a Dumpy Level.

If the instrument is a Dumpy Level:

1. Remove level bar and center in the same way that the alidade and the circle assembly are removed on a transit.

2. Remove clamp mechanism as described for the transit (page 28).

3. Remove half ball and leveling screws as described for the transit on page 28.

All surfaces that need to be cleaned and lubricated are now exposed. Re-assemble the instrument in reverse order.

LEVEL ADJUSTMENTS

TILTING LEVEL ADJUSTMENTS

First read the general directions under "Adjustments" on pages 31-33.

Object. To make the coincidence of the ends of the bubble occur when the line of sight is horizontal.

Test. Make the test for the peg adjustment as described for the telescope level of the transit.

Adjustment. After the target has been set, bring the line of sight on it by turning the micrometer screw.

There are three capstan head screws at the back of the bubble housing. Loosen the two

outside screws. Turn the middle screw until the ends of the bubble are in coincidence. Retighten the two outside screws.

No other adjustments are necessary.

ZEISS SELF-LEVELING LEVEL ADJUSTMENTS

Before it is assumed that adjustments are necessary, it is essential to make sure that any apparent need for adjustment is actually due to the condition of the instrument and is not caused by deficiencies in the test. To test an instrument properly, observe the following precautions:

1. Choose a firm support for the instrument. Usually this can be found only outdoors. The floor of a building, even when made of concrete, will deflect when the observer moves around the instrument.

2. If possible, choose a cloudy day. If the sun is shining, the work must be carried out in the shade, but in good light.

3. The instrument must have time to accommodate itself to temperature. This requires 30 minutes to an hour, depending on how great a temperature difference exists between the place of storage and the outdoor temperature.

4. Be on the lookout for *creep* when adjusting the circular level. Creep is caused by tripod settlement, or by the temperature of the instrument changing. This is particularly apt to happen if the instrument has just been brought out-of-doors or is exposed to body or other radiant heat. After setting a bubble or the line of sight, let it stand a few seconds to see that no movement occurs.

5. The line of sight of a Zeiss Level seldom gets out of adjustment. Adjustment should not be undertaken except as the result of several sets of tests made after the circular level has been carefully adjusted.

To Adjust the Friction of the Leveling Screws. After considerable use the leveling

screws may become slightly loose where they are threaded into the tribrach or leveling head. This play is not serious when using the instrument as a level. However, if the instrument has a horizontal circle and it is used to measure angles, play in the leveling screws will affect the accuracy of this measurement. To eliminate the play, turn each leveling screw clockwise until a small screw can be seen on the side of the leveling screw bushing. The leveling screw is threaded into the bushing. The screw is located in that portion of the bushing which is toward the vertical center line of the instrument. It can be seen by looking across the hold down plate outward toward the bushing.

Tightening this screw increases the compression of a small spring, which in turn, applies pressure to the screw threads. Avoid tightening the screw to such an extent that the leveling screw is difficult to turn.

To Replace the Plastic Washers On the Tangent Screws. Hold the left–hand screw stationary and unscrew the right–hand screw until it comes off. Pull out the two screws and replace the washers.

1\. ***Object.*** To make the circular bubble center when the azimuth axis is vertical.

This adjustment is of great importance on the Zeiss Level. The accuracy of the instrument is considerably increased when the azimuth axis is as nearly vertical as it is possible to set it with the circular bubble. The compensator mechanism is designed so that the compensator is at the center of its movement when the azimuth axis is vertical. The accuracy with which the compensator corrects for the residual tilt of the telescope is greatest when the compensator is at its center of movement.

Test. Turn the telescope in azimuth until it is parallel with a pair of leveling screws. Center

the bubble precisely in the ring with the leveling screws. Turn the telescope 180° in azimuth until it is parallel with the same pair of leveling screws. The bubble should return to center. If it does not, adjustment is required.

Adjustment. In the circular level mount, on the latest models, there are four slotted-capstan head adjusting screws. The outer edge of the circular level mount is a spherical surface, and is precisely fitted in a recess in the box housing. With a screwdriver or adjusting pin loosen or moderately tighten all four screws until they are seated. Repeat the test as the bubble may be moved further out of adjustment.

If the bubble fails to center, bring it halfway toward the center with the leveling screws. To bring it the rest of the way, loosen the slotted-capstan head screw that lies in the direction of desired bubble movement. Tighten the opposite screw until the bubble is in line with the other two adjusting screws. A final adjustment of these two adjusting screws should then bring the bubble to the center. Turn the telescope 180° in azimuth until it is parallel to the same pair of leveling screws. If the bubble fails to center, repeat the adjustment. When the adjustment is complete all of the screws must be firm but not tight. The bubble should remain exactly centered in the ring as the telescope is turned in every direction. If it does not, repeat this adjustment. On earlier models, it is first necessary to unscrew the lock ring at the base of the observation prism and remove the prism unit. If the instrument is not equipped with an observation prism unscrew the adjusting-screw-guard ring which surrounds the circular level. This will expose three slotted head adjusting screws. The circular vial is supported by a resilient washer which forces it upward against the screws. With a screw driver loosen or moderately tighten all three screws until they are seated. Repeat the test as the bubble may be

moved further out of adjustment. If the bubble fails to center bring it half way toward the center with the leveling screws and the balance of the way by tightening the most logical adjusting screws until the bubble is precisely centered. Do not loosen any one of them. Turn the telescope 180° in azimuth until it is parallel to the same pair of leveling screws. If the bubble fails to center, repeat the adjustment.

When the adjustment is complete all of the screws must be firm but not tight. The bubble should remain exactly centered in the ring as the telescope is turned in every direction. If it does not, repeat this adjustment.

2. ***Object.*** To make the line of sight level.

Test. Make the test for the peg adjustment as described for the telescope level for the transit.

Adjustment. After the target has been set, unscrew the reticule cover. This is a circular cap 1$\frac{5}{16}$ inch in diameter at the end of the telescope just in front of the eyepiece. A small capstan head screw will be exposed just above the eyepiece. This raises and lowers the cross lines against a spring loading. Bring the cross line on the target by regulating this screw.

No other adjustments are necessary.

DUMPY LEVEL ADJUSTMENTS

First read the general directions under "Adjustments" on pages 31-33.

For convenience, the bubble should center when the azimuth axis is placed in the direction of gravity. This relationship makes it unnecessary to relevel the instrument more than a slight touch, for any observation. But if the adjustment necessary to obtain this relationship is made, then the complete peg adjustment must be carried out immediately, as the bubble will no longer center when the line of sight is horizontal.

DUMPY LEVEL

The Level Tube

1. ***Object.*** To make the bubble center when the azimuth axis is placed in the direction of gravity.

Test. Level over each of the two pairs of opposite leveling screws and center the bubble over one pair. Turn the instrument 180° in azimuth. The bubble should center.

Adjustment. Bring the bubble half-way toward the center with the leveling screws. Center the bubble with the capstan adjusting screw or nut or, on some dumpy levels, with the opposing nuts at one end of the tube.

The Cross Line Reticule

2. ***Object.*** To make the horizontal cross line lie in a plane perpendicular to the azimuth axis.

Test. Aim at some well defined point and turn the telescope slightly left and right with the tangent screw. The horizontal cross line should remain on the point.

Adjustment. Loosen slightly two adjacent reticule adjusting screws. Tap the sides of the screws until the cross line is rotated to its correct position. Tighten the same screws.

3. ***Object.*** To make the line of sight level when the bubble is centered.

Test. Make the test for the peg adjustment as described for the telescope level of the transit.

Adjustment. After the target has been set, focus on the rod and center the bubble. Bring the horizontal cross line on the target with the reticule adjusting screws. Loosen a side screw. Move the upper and lower screws by small increments. Finally tighten the side screw previously loosened.

PLANE TABLE ALIDADES

Plane table surveys made with adequate telescopic alidades are the best means of mapping small areas and of filling in details between survey control points. They are also of great importance as an adjunct to aerial mapping in certain areas. Aerial mapping is impossible over areas lacking objects that appear on the photographs. Large areas of sand or uniform vegetation are examples. Dense deciduous forest areas can be mapped only when the leaves are off the trees, and dense conifer forests cannot be mapped by aerial methods. Certain political and private boundaries do not appear on the photographs, and deep valleys are often concealed.

The accuracy of aerial maps depends in part on the density of survey control, particularly vertical control. Control points can be selected only after the photographs have been taken. It is always necessary to tie these points to sparsely distributed basic control points established before the photographs are taken. Plane table leveling and traverse have been used extensively for this purpose.

Plane table mapping has three important advantages over other types of ground mapping:

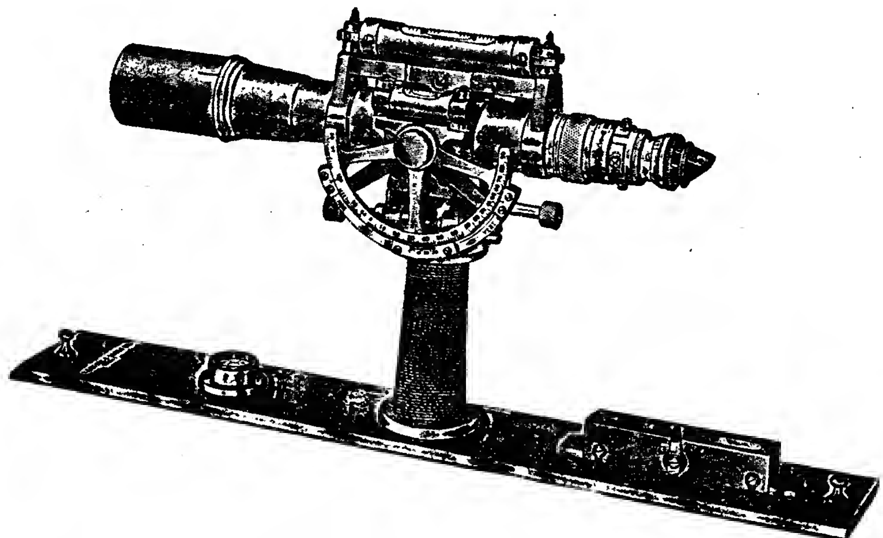
1. All direction measurements are instantly recorded on the map. The intervening processes of recording field notes and plotting them are eliminated.

2. The map is constructed at once, in the field, so that no permanent records are necessary other than the map itself.

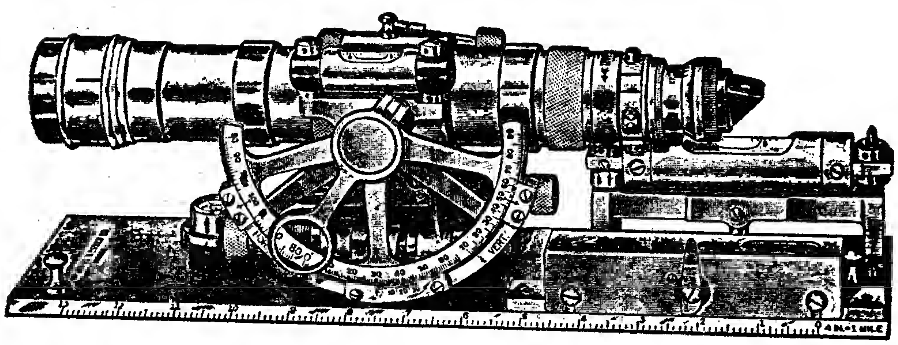
3. The topographer sees the ground that he is mapping. He can draw a more perfect representation of the ground and yet use fewer field observations.

CONVENTIONAL ALIDADES

Conventional alidades of the type exemplified by K&E PARAGON Geological Survey Alidade No. 76 0020 and K&E PARAGON Expedition Alidade 76 0030 are well known.



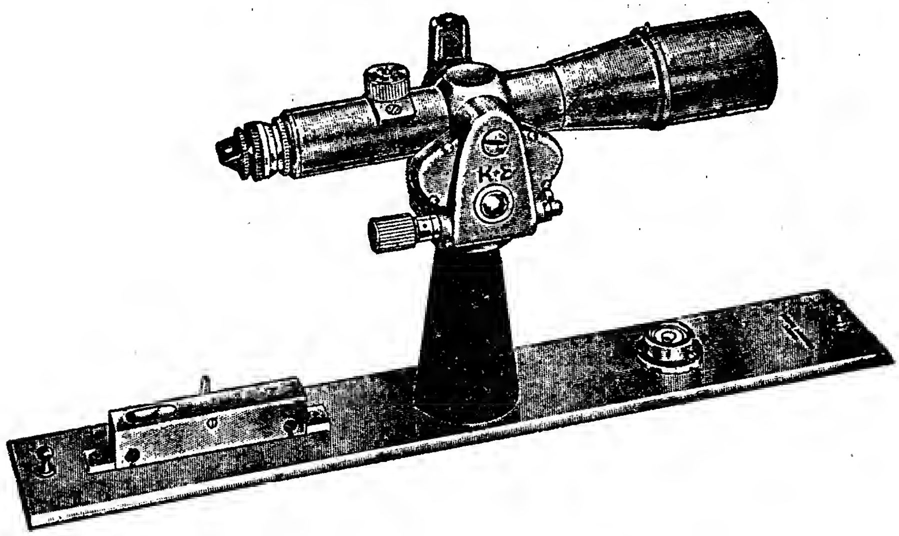
K&E PARAGON® Geological Survey Alidade 76 0020



K&E PARAGON® Expedition Alidade 76 0030

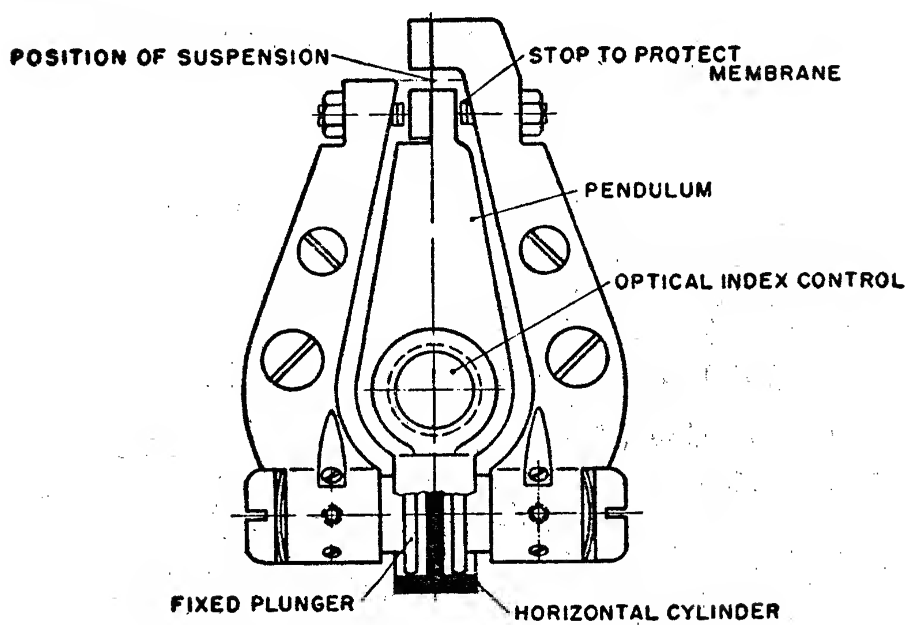
K&E PARAGON® SELF-INDEXING ALIDADES

In cooperation with the U. S. Geological Survey, K&E has developed a radically new alidade, the K&E PARAGON Self-Indexing Alidade.



K&E PARAGON® Self-Indexing Geological Survey Alidade 76 0000

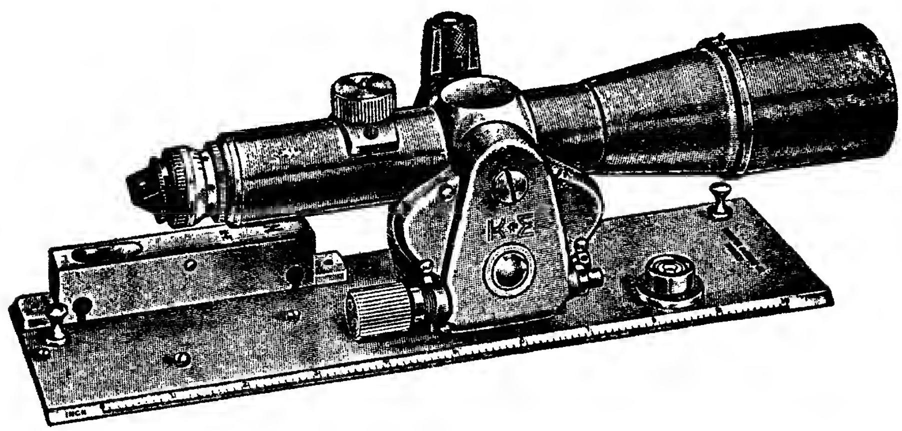
This instrument has a pendulum device that *automatically* sets the indices used to read the horizontal and vertical multipliers and the elevation angle scale. It thus corrects automatically for the slight residual tilts of the plane table. The scales are read *optically* and the instrument gives results that are approximately four times as accurate as those attained with conventional alidades.



Pendulum Damping Mechanism

The pendulum is suspended by a membrane and its swing is air-damped as shown in the illustration. An optical part mounted in the pendulum brings the correct scale readings to the index.

Included in the design of the alidade are many basic changes made possible by modern precise manufacturing methods. The telescope is fixed in its axle and the reticule is fixed in the telescope, so that only one field adjustment is required—to zero-in the index. No tangent clamp



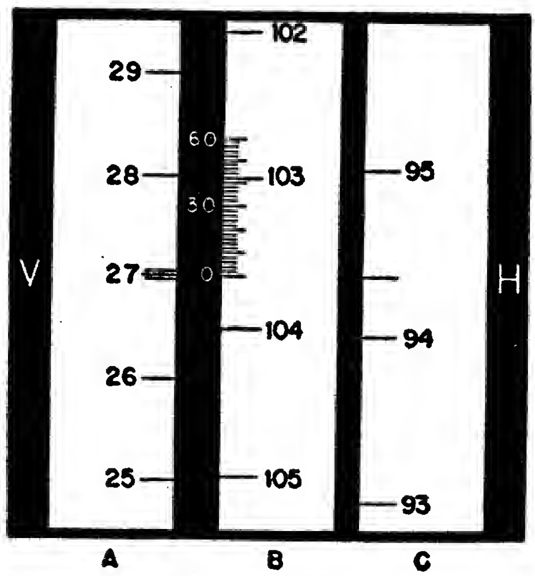
K&E PARAGON® Self-Indexing Expedition Alidade 76 0010

is used. Instead, a flat resilient washer holds the telescope at the angle at which it is placed. The degree of friction can be regulated by a large screw that can be turned with a coin. The precise setting is made with the one tangent screw.

The optics of the main telescope have been completely redesigned. The main telescope has an achromatic doublet objective and an achromatic triplet eyepiece. The power is 16 diameters and internal focusing is used so that the stadia additive constant (f+c) is negligible. All lens

surfaces are coated except the first and last. The focusing knob is on top for convenience. Open finder sights are provided.

View through Scale-Reading Eyepiece



A. Vertical Scale reads 27.0

B. Elevation Angle Scale reads 103° 42′ (See page 106)

C. Horizontal Multiplier reads 94.4

The optical scale-reading eyepiece provides a view of the scales as shown in the illustration. All three scales are visible simultaneously. No vernier is required and all three scales can be read from a single point. The light which illuminates the scales is collected by a large, almost semi-spherical lens. This eliminates the need for a mirror that must be regulated for each sight, as conventionally used on optically read instruments.

The compass is of the induction-damped type.

THE USE OF CONVENTIONAL ALIDADES

Space does not permit a description of mapping with an alidade and plane table. The reader is referred to the many excellent available texts that cover this subject.

In the use of Alidades, the following are accomplished as described for transits on pages 17-21:

1. To tighten tripod shoes.
2. To adjust tripod hinges.
3. To focus the eyepiece.
4. To avoid contact with the instrument.
5. To transport the instrument.

INDUCTION-DAMPED COMPASS NEEDLE

The compass needle on modern K&E alidades is very strongly magnetized and it is damped by induction. Even though it appears to be sluggish, it actually moves freely. It is much more sensitive, accurate and dependable than the conventional compass needle.

The strong magnetism of the needle makes it dip more than conventional needles. To adjust the dip, loosen the four screws that hold the compass box cover. Remove the cover and lift off the needle, holding it by its center. Loosen the lifter spring screw so that the needle will swing free when replaced. Move the weight until the needle will balance when placed on its pivot.

Test for Sensitivity of Needle

Center the needle by aiming the alidade in azimuth. Swing the needle off center by bringing a steel key or other magnetic object near the needle momentarily. Note where the needle comes to rest. If it does not return exactly to its original position, the pivot is damaged and must be replaced.

THE STADIA ARC AND THE VERTICAL ARC GRADUATIONS

K&E Alidades Nos. 76 0020 and 76 0030 are equipped with the K&E Stadia Arc No. 74 0510. The use of these arcs facilitates stadia surveying by eliminating measurements of the vertical angle and the use of tables. For a more detailed description of stadia surveying see page 104.

THE USE OF K&E PARAGON® SELF-INDEXING ALIDADES 76 0000 & 76 0010

The Self-Indexing Alidade has a number of features that make it so different from conventional alidades that K&E includes these instructions for its use.

The Strap and Clasp. Mildew-proof, damp-resistant webbing is used for the strap. This material never drys out and breaks as leather does. It was chosen by the U. S. Geological Survey after exhaustive tests to determine the material that would give the best and longest service. The clasp, when closed, seems loose. However, it will not open by itself. It is made this way so that when the instrument is carried, the strap will not become taut until its center is 2 or 3 inches above the case. This gives enough freedom to reduce the strain on the strap and case and to give plenty of room for the fingers.

The Grip. The resilient plastic gives a nearly perfect grip and does away with the wrapped cord grip that frequently loosened.

The Circular Level. The circular level has two circles. The inner circle is used for accurate leveling. The outer circle is a safety device. When the bubble is within the outer circle, the pendulum that sets the index is sure to be free to swing.

The Compass. The compass needle is very strongly magnetized and it is damped by induction. Even though it appears sluggish, it actually moves freely. It is much more accurate and dependable than conventional needles.

The strong magnetism of the needle makes it dip more than conventional needles. To adjust the dip, loosen the four screws at the sides of the compass box cover. Slide the cover upwards and lift off the needle, holding it by its center. Loosen the lifter screw so that the needle will swing free when replaced. Move the weight until the needle will balance when placed on the pivot.

To Aim the Telescope Vertically. There is no clamp to hold the telescope in position. The slope of the telescope is retained by a special spring-friction device. Aim the telescope by hand and make the final adjustment with the tangent screw. The open sights on the top of the telescope facilitate aiming.

The degree of friction can be regulated by turning the large screw at the right-hand end of the elevation axis. A coin will fit the slot in the screw.

The Tangent Screw. The tangent screw will move the telescope through a range of over $\pm 5°$. The center and limits of the range are marked for the convenience of the observer so that he can center the screw when he desires. The marks are on the tangent screw collar over which the knurled head of the tangent screw turns. Red circles around the collar show the limits of range; a black circle around the collar shows the center of range.

If desired, the tangent screw can be reversed so that it can be operated from the front of the instrument. To make this change, unscrew the

cap mounted on the standard in line with the tangent screw. A coin or screw driver may be used. A spring and plunger should come out with the cap. If they do not, turn the instrument objective end down and tip it until they come out. Unscrew the tangent screw assembly. Replace the collar and the tangent screw before replacing the spring, plunger and cap.

To Read the Vertical Arcs.* Once the instrument is aimed, the arcs can be read immediately. No index level need be set, as the automatic indexing feature takes over. The arcs are read at the eyepiece located at the top of the left-hand standard. While looking down through the eyepiece, focus it by turning it until the graduations are clear.

The field of view appears as shown in the figure in the K&E Solar Ephemeris, under the heading "Plane Table Alidades." See page 65. There are two vertical black bands in the field of view. To the right of the narrower band is a single line marked "H." This is index for the horizontal stadia multiplier. At the left of the wide band is a paired-line index marked "V" for the vertical stadia scale. At the right edge of the wide band is a scale which is the index for the zenith angle arc.

The horizontal multiplier is read directly; in this case 94.4. The vertical scale is read 27.0 and 50 is subtracted from it giving − 23.0. To avoid a minus reading the vertical multiplier values are arbitrarily increased by 50. Thus, 50 must be subtracted from each reading to obtain the true value.

The zenith distance is the angle measured down from the zenith to the line of sight. It is

*If this is attempted indoors, turn the right-hand side of the instrument toward a window.

therefore the complement of the vertical angle. To find the vertical angle, subtract the zenith distance from 90°. When a minus sign results, the vertical angle is minus.

To read the zenith distance, first read the number which is adjacent to the small scale, 103. This gives the number of degrees. The small scale reads in minutes at intervals of two minutes. Read this scale at the point where the degree mark coincides. In this example the reading is 42. The complete reading is therefore 103°42′. The vertical angle is then computed:

$$\begin{array}{lr} & 90°00' \\ \text{Zenith Distance} - & 103°42' \\ \hline \text{Vertical Angle} \quad - & 13°42' \end{array}$$

While reading the arcs, be careful not to disturb the plane table. If it is deflected, the slope of the line of sight will be changed and thus move above or below the point of aim. The automatic index will then give the reading for this new slope and not the slope desired.

To Make an Observation. Two methods are recommended for making observations, the stadia arc method and the zenith angle method. An example of each is given. In both, assume that the elevation of the instrument is 525.7. Note that the stadia additive constant is negligible in this instrument so that it does not appear in the computations.

The Stadia-Arc Method. Determine the stadia intercept (5.30 for example). Set the vertical stadia scale at the nearest exact value (27.0). Read the rod at center horizontal cross line (4.7). Read the horizontal multiplier (94.4).

Make the following computations, using an ordinary slide rule for the multiplications.

5.30(94.4)	= 500	Hor. Dist.
27.0 − 50	= −23.0	
5.30(−23.0)	= −121.9	Diff. Elev.

Instrument Elevation	525.7
Difference in Elevation	− 121.9
	403.8
Rod	− 4.7
Elevation	399.1

The Zenith-Distance Method. Determine the stadia intercept (5.30). Read the Zenith Distance (103°42′) and the rod (4.7). Make the following computations, using a stadia slide rule for the multiplications.

$$90° - 103°42' = -13°42'$$

Set the slide index at 530
Set the indicator at 13°42′ for H and read 500
Set the indicator at 13°42′ for V and read 121.9

Compute the elevation as before.

To Install the Prismatic Eyepiece. Hold the black knurled eyepiece focusing ring stationary and unscrew the smooth black ring at the end of the telescope. Screw the prismatic eyepiece in its place.

Adjustments. There is only one field adjustment. This is described under "Field Adjustments" pages 86-88. First read general directions under "Adjustments" on pages 31-33.

Shop Adjustments. There are certain shop adjustments that may be necessary if the instrument is damaged. To make them, refer to "Disassembly and Adjustments" page 88.

CARE OF ALIDADES

Same as for transits (pages 21-22).

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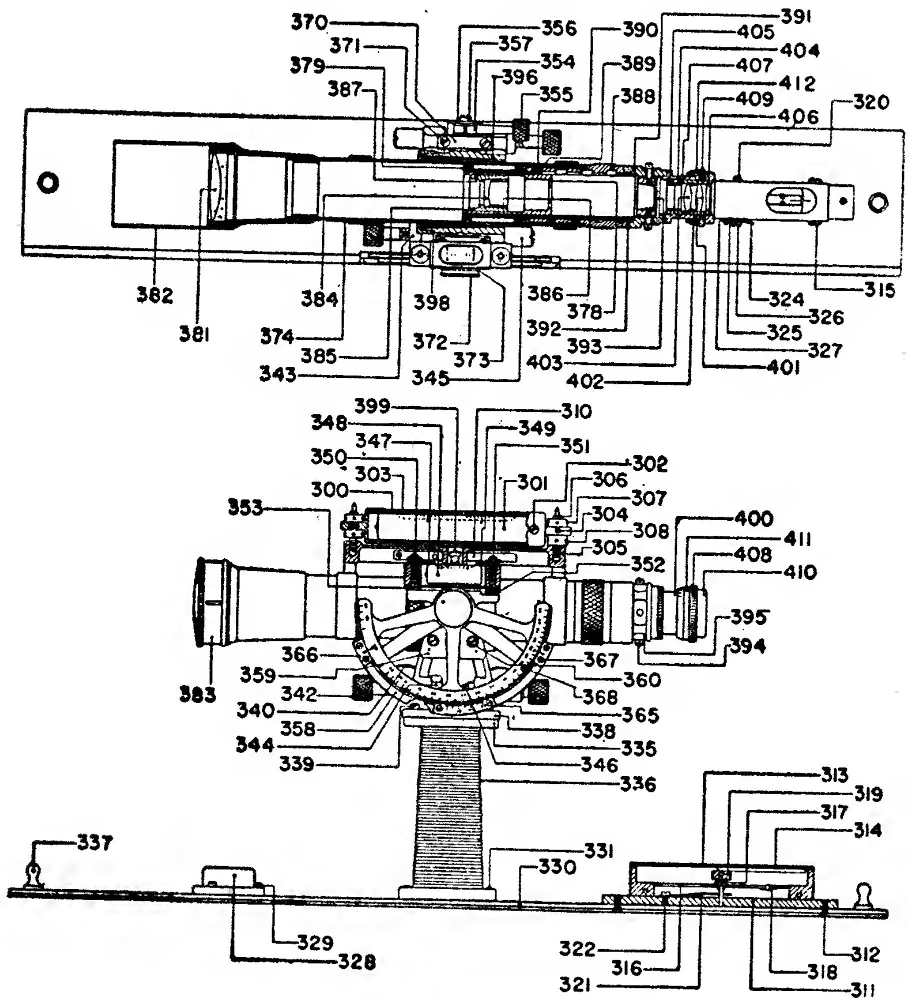
GEOLOGICAL SURVEY ALIDADE



5225-300 Striding Level Vial, Tube and Ends complete
301 Str. Lev. Vial only
302 Str. Lev. Vial Tube End Lock Screw
303 Str. Lev. Tube Cover
304 Stri. Level Adj. Screw
305 Str. Lev. Bracket
306 Striding Level Post
307 Striding Level Adjusting Nut
308 Str. Lev. Fixed Nut
309 Str. Lev. Bracket Lock Screw (Not shown. See 76 0030)
310 Striding Level Spring Release
311 Trough Compass Base
312 Tr. Comp. Base Screw
313 Tr. Comp. Cover
314 Tr. Comp. Cover Glass
315 Tr. Comp. Cover Screw
316 Tr. Comp. Needle
317 Tr. Comp. Needle Cap
318 Trough Compass Needle Balance Clip
319 Trough Compass Needle Spacer
320 Trough Compass Needle Spacer Screw
321 Trough Compass Needle Lifter
322 Trough Compass Needle Lifter Screw
323 Trough Compass Needle Lifter Cam (not shown)
324 Trough Compass Needle Lifter Lever
325 Tr. Comp. Needle Lifter Lever Washer
326 Tr. Comp. Needle Lifter Lever Screw

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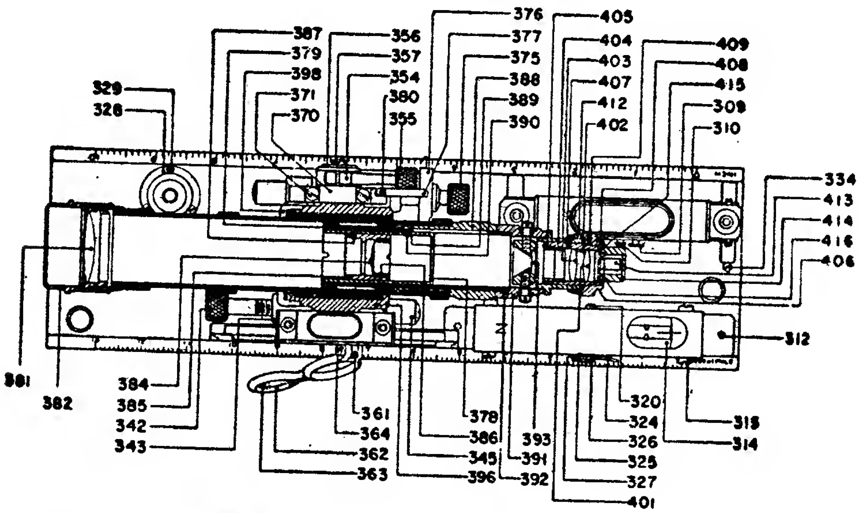
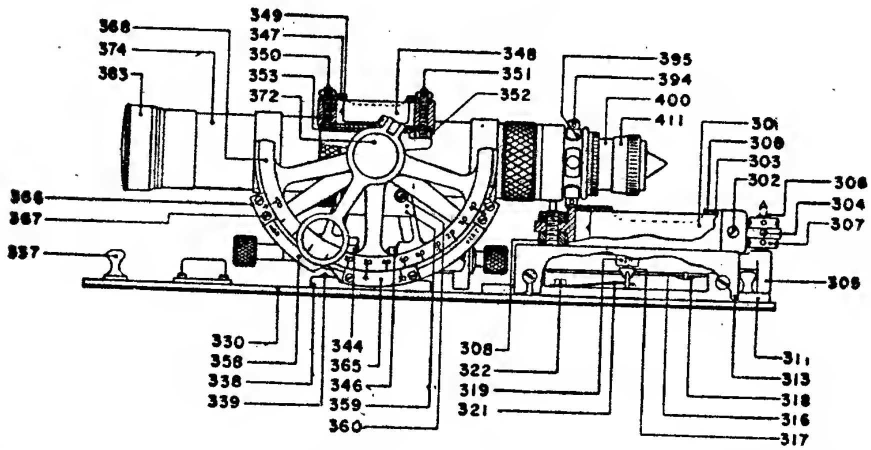
GEOLOGICAL SURVEY ALIDADE

5225-327 Trough Compass Needle Lifter Lever Stop Screw
328 Circular Level
329 " " Screw
330 Base Plate
331 " " Screw
335 Pedestal
336 " Grip Cord
337 Base Plate Knob
338 Standard
339 " Screw
340 Telescope Stop
341 " " Screw (not shown)
342 Tangent Screw
343 " " Bushing
344 Tangent Screw Bushing Nut
345 Tangent Screw Spring Box
346 Tangent Screw Spring Box Plunger
347 Control Bubble Vial, Tube, & Ends complete
348 Control Bubble Vial only
349 Control Bubble Tube Cover
350 Control Bubble Fixed Post
351 Control Bubble Adjustable Post
352 Control Bubble Adjusting Nut
353 Control Bubble Fixed Nut
354 Telescope Clamp
355 " " Clamp Screw
356 Telescope Clamp Washer
357 Telescope Clamp Washer Screw
358 Vernier Arc
359 " " Bearing Bracket
360 Vernier Arc Bearing Bracket Screw
365 Vertical Arc Vernier
366 Stadia Index
367 Vernier & Index Screw
368 Vertical Arc
369 " " Screw (not shown)
370 Trunnion Cap
371 " " Screw
372 Rosette
373 Spacing Washer
374 Telescope Barrel
378 " Draw Tube
379 " " " Sleeve
381 Objective Lens & Mount
382 Sunshade
383 Telescope Cap
384 " Focusing Lens
385 Telescope Focusing Lens Mount
386 Telescope Focusing Lens Lock Ring
387 Telescope Focusing Lens Mount Lock Screw
388 Telescope Focusing Cam
389 Telescope Focusing Cam Shoe
390 Telescope Focusing Cam Shoe Screw
391 Eyepiece Body
392 " " Set Screw
393 Reticule
394 " Adjusting Screw
395 Reticule Adjusting Screw Shutter
396 Axle
397 " Stop Screw (not shown)
398 Telescope Clamp Ring
399 Striding Level Mounting Stud
400 Eyepiece Sleeve
401 Eye Lens
402 " " Spacing Ring
403 Eyepiece Field Lens
404 " " " Spacing Ring
405 Eyepiece Field Lens Lock Ring
406 Eyepiece Mount
407 " Cam Screw
408 " Focusing Ring
409 Eyepiece Focusing Ring Lock Screw
410 Eyepiece Cap
411 " Diopter Scale
412 Eyepiece Diopter Scale Screw

When ordering parts, state Serial No. of instrument.

K&E PARAGON®
EXPEDITION ALIDADE



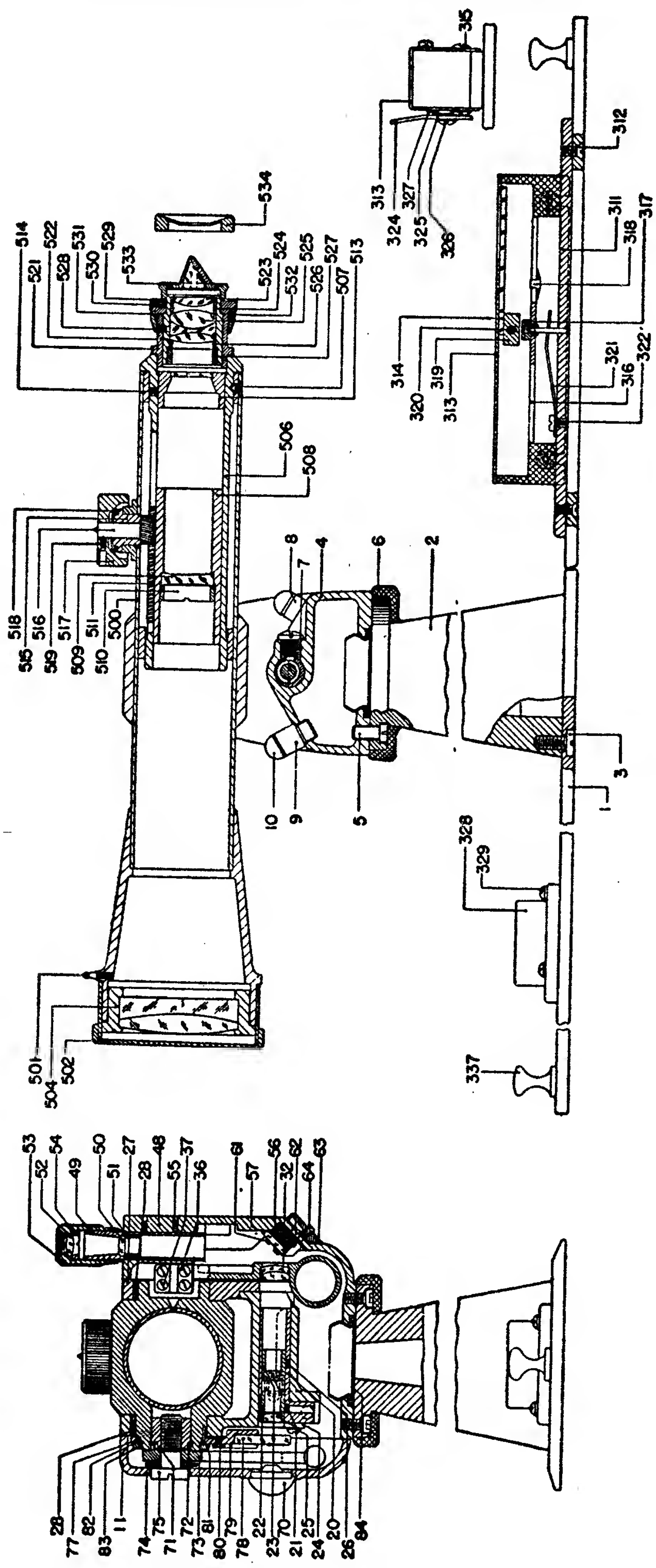


5230-300 Striding Level Vial, Tube & Ends complete
301 Str. Lev. Vial only
302 Str. Lev. Tube End Lock Screw
303 Str. Lev. Tube Cover
304 Str. Lev. Adjusting Screw
305 Str. Lev. Bracket
306 Str. Lev. Post
307 Str. Lev. Adj. Nut
308 Str. Lev. Fix. Nut
309 Str. Lev. Bracket Lock Screw
310 Str. Lev. Spring Release
311 Trough Compass Base
312 Tr. Comp. Base Screw
313 Tr. Comp. Cover
314 Tr. Comp. Cover Glass
315 Tr. Comp. Cover Screw
316 Tr. Comp. Needle
317 Tr. Comp. Needle Cap
318 Tr. Comp. Needle Balance Clip
319 Tr. Comp. Needle Spacer
320 Tr. Comp. Needle Spacer Screw
321 Tr. Comp. Needle Lifter
322 Tr. Comp, Needle Lifter Screw
323 Tr. Comp. Needle Lifter Cam (not shown)
324 Tr. Comp. Needle Lifter Lever
325 Tr. Comp. Needle Lifter Washer
326 Tr. Comp. Needle Lifter Screw

5230-327 Trough Compass Needle Lifter Stop Screw
328 Circular Level
329 " " Screw
330 Base Plate
332 Striding Level Bracket Stud (not shown)
334 Striding Level Bracket Stop Screw
337 Base Plate Knob
338 Standard
339 " Screw
342 Tangent Screw
343 " " Bushing
344 Tangent Screw Bushing Nut
345 Tangent Screw Spring Box
346 Tangent Screw Spring Box Plunger
347 Control Bubble Vial, Tube, & Ends complete
348 Cont. Bub. Vial only
349 Cont. Bub. Tube Cover
350 Cont. Bub. Fixed Post
351 Cont. Bub. Adjustable Post
352 Cont. Bub. Adjusting Nut
353 Cont. Bub. Fixed Nut
354 Telescope Clamp
355 " " Clamp Screw
356 Telescope Clamp Washer
357 Telescope Clamp Washer Screw
358 Vernier Arc
359 " " Bearing Bracket
360 Vernier Arc Bearing Bracket Screw
361 Magnifier Frame Holder
362 Magnifier Frame
363 " Glass
364 " Frame Clamp Screw
365 Vertical Arc Vernier
366 Stadia Index
367 Vernier and Index Screw
368 Vertical Arc
369 " " Screw (not shown)
370 Trunnion Cap
371 " " Screw
372 Rosette
374 Telescope Barrel
375 Gradienter Screw
376 " " Drum
377 Gradienter Index
378 Draw Tube
379 " " Sleeve
380 Gradienter Index Screw
381 Objective Lens & Mount
382 Sunshade
383 Telescope Cap
384 " Focusing Lens
385 Telescope Focusing Lens Mount
386 Telescope Focusing Lens Lock Ring
387 Telescope Focusing Lens Mount Lock Screw
388 Focusing Cam
389 " " Shoe
390 " " " Screw
391 Eyepiece Body
392 " " Set Screw
393 Reticule
394 " Adjusting Screw
395 Reticule Adjusting Screw Shutter
396 Axle
397 Axle Stop Screw (not shown)
398 Telescope Clamp Ring
399 Striding Level Mounting Stud (not shown)
400 Eyepiece Sleeve
401 Eye Lens
402 " " Spacing Ring
403 Eyepiece Field Lens
404 " " " Spacing Ring
405 Eyepiece Field Lens Lock Ring
406 Eyepiece Mount
407 " Cam Screw
408 " Focusing Ring
409 Eyepiece Focusing Ring Lock Screw
411 Eyepiece Diopter Scale
412 " " " Screw
413 Eyepiece Prism
414 " " Mount
415 Eyepiece Prism Mount Flange
416 Eyepiece Prism Mount Flange Screw

When ordering parts, state Serial No. of instrument.

K&E PARAGON®—SELF-INDEXING
GEOLOGICAL SURVEY ALIDADE



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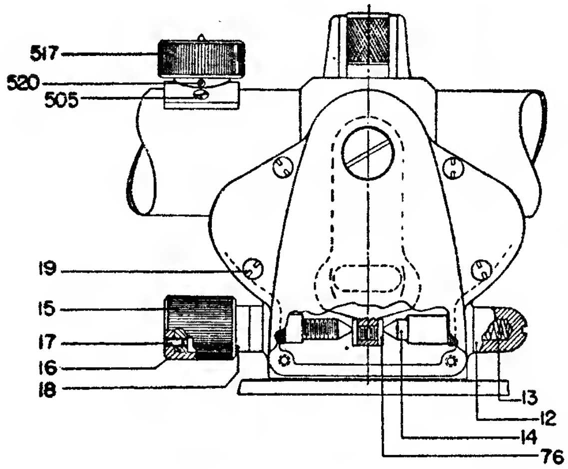
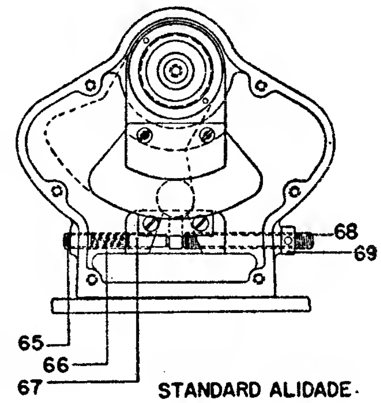
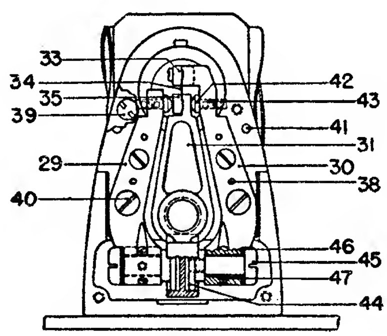
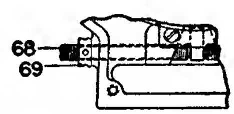
GEOLOGICAL SURVEY ALIDADE





STANDARD ALIDADE·





GEOLOGICAL SURVEY ONLY

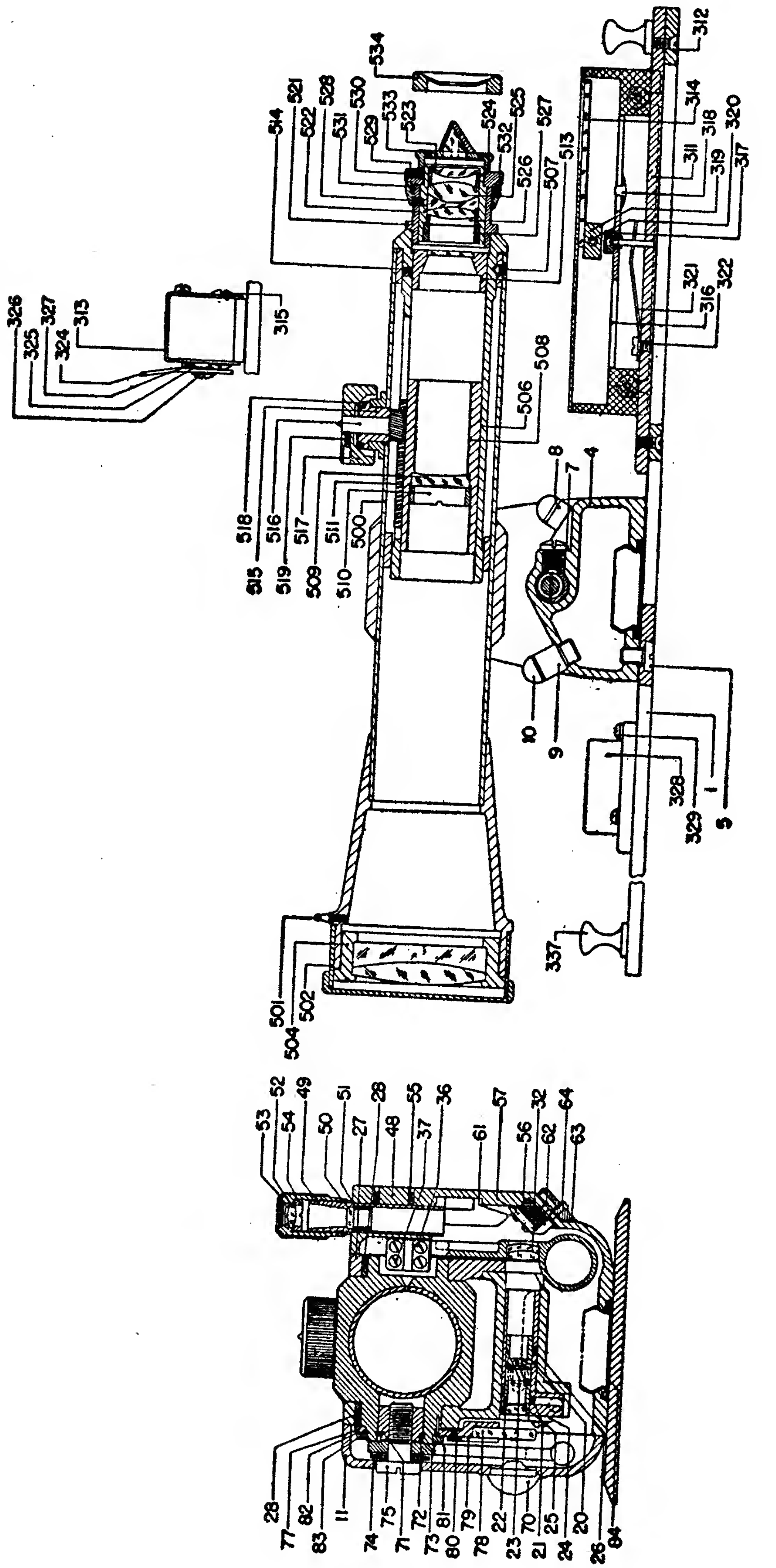
5226-1 Base Plate
2 Pedestal
3 Base to Pedestal Screw
4 Standard
5 Standard Mounting Screw
6 Protective Housing
7 Opening Adjustment Screw
8 Right Bumper Mount
9 Left Bumper Mount
10 Telescope Bumper
11 Right Cover
12 Tangent Screw Plunger Bushing
13 Tangent Screw Spring
14 Tangent Screw Spring Plunger
15 Tangent Screw Cap
16 Tangent Screw
17 Tangent Screw Cap Screw
18 Tangent Screw Bushing
19 Right & Left Cover to Standard Screw
20 Regulator Lens Mount Tube
21 Regulator Lens
22 Regulator Lens Mount
23 Regulator Lens Mount
24 Regulator Tube Plate
25 Regulator Tube Plate Screw
26 Regulator Lens Mount Screw

5226-27 Standard Plate
28 Friction Plug
29 Left Pendulum Bracket
30 Right Pendulum Bracket
31 Pendulum
32 Erector Lens
33 Membrane Hinge Plate
34 Membrane Hinge
35 Membrane Hinge Plate
36 Membrane Hinge Plate Screw
37 Membrane Hinge Plate Screw
38 Plate to Standard Pin
39 Left Cover to Standard Screw
40 Bracket & Plate to Standard Screw
41 Left Cover Pin
42 Pendulum Bracket Bumper
43 Bumper Screw
44 Pendulum Piston
45 Pendulum Screw
46 Piston Spring Washer
47 Piston Set Screw
48 Left Cover
49 Focusing Tube
50 Reticule
51 Reticule Lock Ring
52 Eyepiece Lens
53 Focusing Tube Cap
54 Eyepiece Lens Lock Ring
55 Focusing Tube Set Screw
56 Mirror Mount
57 Scale Mirror
58 Right Front Mirror Spring †
59 Left Front Mirror Spring †
60 Side Front Mirror Spring †
†Not shown
61 Mirror Spring Screw
62 Mirror Mount Screw
63 Mirror Mount Cover
64 Mirror Mount Cover Screw
65 Vertical Scale Index Adjustment Screw
66 Vertical Scale Index Adjustment Screw Spring
67 Vertical Scale Index Adjustment Screw Plunger
68 Vertical Scale Index Adjustment Screw
69 Vertical Scale Index Adjustment Screw Nut
70 Light Gathering Lens
71 Tangent Screw Arm Nut
72 Tangent Screw Arm Retaining Ring
73 Tangent Screw Arm
74 Tension Plate
75 Tangent Adjusting Screw
76 Tangent Screw Arm Screw
77 Scale Mount
78 Scale
79 Scale Plate
80 Plate to Scale Mount Screw
81 Scale Mount to Barrel Pin
82 Scale Mount Washer
83 Scale Mount Nut
84 Button Plug
311 Trough Compass Base
312 Tr. Comp. Base Screw
313 Tr. Comp. Cover
314 Tr. Comp. Cover Glass
315 Tr. Comp. Cover Screw
316 Tr. Comp. Needle
317 Tr. Comp. Needle Cap
318 Tr. Comp. Needle Balance Clip
319 Tr. Comp. Needle Spacer
320 Tr. Comp. Needle Spacer Screw
321 Tr. Comp. Needle Lifter
322 Tr. Comp. Needle Lifter Screw
323 Tr. Comp. Needle Cam (Not shown)
324 Tr. Comp. Needle Lifter Lever

5226-325 Tr. Comp. Needle Lifter Lever Washer
326 Tr. Comp. Needle Lifter Lever Screw
327 Tr. Comp. Needle Lifter Lever Stop Screw
328 Circular Level
329 Circular Level Screw
337 Base Plate Knob
500 Telescope Barrel & Axle
501 Telescope Front Sight
502 Telescope Cap
503 Telescope Sunshade (Not Shown)
504 Objective Lens & Mount
505 Pinion Saddle to Barrel Screw
506 Body Tube
507 Body Tube Set Screw
508 Telescope Draw Tube
509 Telescope Focusing Lens
510 Telescope Focusing Lens Lock Ring
511 Telescope Focusing Pinion Rack
512 Telescope Focusing Pinion Rack Screw (Not Shown)
513 Reticule & Mount
514 Reticule Mount Set Screw
515 Telescope Pinion Mount
516 Telescope Focusing Pinion
517 Telescope Focusing Pinion Head
518 Telescope Focusing Pinion Tension Ring
519 Telescope Focusing Knob Set Screw
520 Telescope Focusing Pinion Mount Set Screw
521 Eyepiece Sleeve
522 Eyepiece Mount
523 Eye Lens
524 Eye Lens Spacing Ring
525 Eyepiece Field Lens
526 Eyepiece Field Lens Spacing Ring
527 Eyepiece Field Lens Lock Ring
528 Eyepiece Cam Screw
529 Eyepiece Focusing Ring
530 Eyepiece Focusing Ring Lock Screw
531 Eyepiece Focusing Diopter Scale
532 Eyepiece Focusing Diopter Scale Screw
533 Holder With Prism Mount
534 Eyepiece Cap

When ordering parts, state Serial No. of instrument.

K&E PARAGON®—SELF-INDEXING
EXPEDITION ALIDADE



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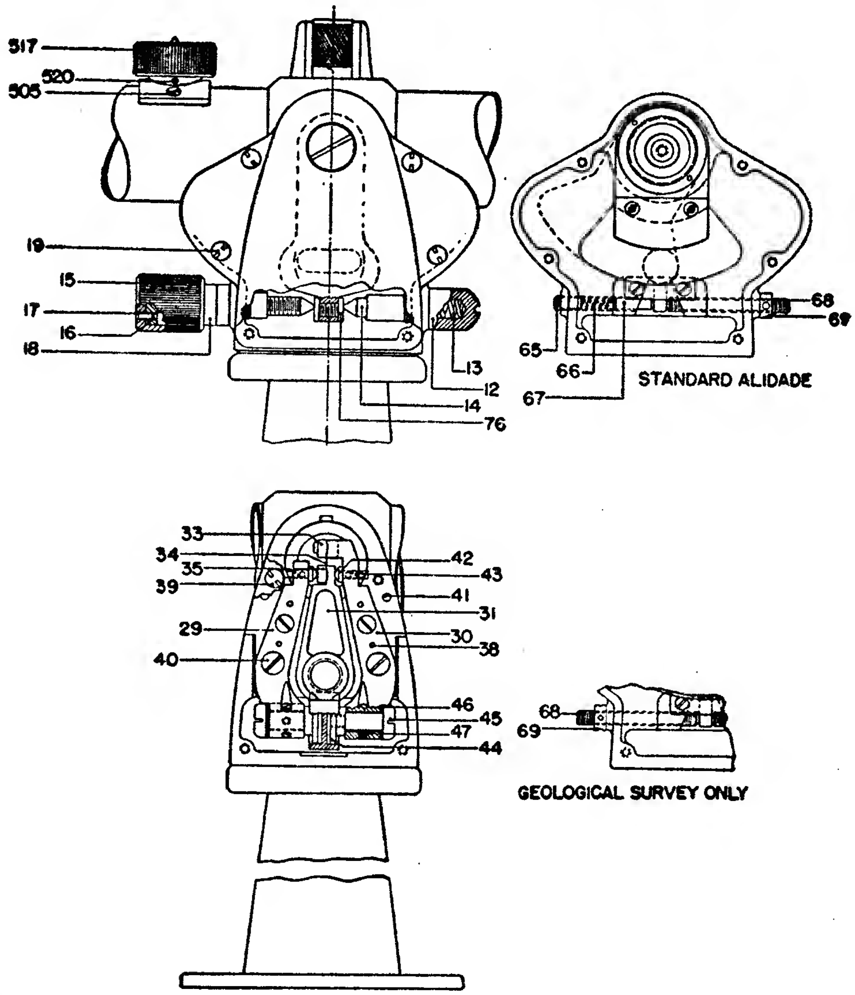
EXPEDITION ALIDADE



5231-1 Base Plate
4 Standard
5 Standard Mounting Screw
7 Opening Adjustment Screw
8 Right Bumper Mount
9 Left Bumper Mount
10 Telescope Bumper
11 Right Cover
12 Tangent Screw Plunger Bushing
13 Tangent Screw Spring
14 Tangent Screw Spring Plunger
15 Tangent Screw Cap
16 Tangent Screw
17 Tangent Screw Cap Screw
18 Tangent Screw Bushing
19 Right & Left Cover to Standard Screw
20 Regulator Lens Mount Tube
21 Regulator Lens
22 Regulator Lens Mount
23 Regulator Lens Mount
24 Regulator Tube Plate
25 Regulator Tube Plate Screw
26 Regulator Lens Mount Screw
27 Standard Plate
28 Friction Plug
29 Left Pendulum Bracket
30 Right Pendulum Bracket
31 Pendulum
32 Erector Lens
33 Membrane Hinge Plate
34 Membrane Hinge

5231- 35 Membrane Hinge Plate
36 Membrane Hinge Plate Screw
37 Membrane Hinge Plate Screw
38 Plate to Standard Pin
39 Left Cover to Standard Screw
40 Bracket & Plate to Standard Screw
41 Left Cover Pin
42 Pendulum Bracket Bumper
43 Bumper Screw
44 Pendulum Piston
45 Pendulum Screw
46 Piston Spring Washer
47 Piston Set Screw
48 Left Cover
49 Focusing Tube
50 Reticule
51 Reticule Lock Ring
52 Eyepiece Lens
53 Focusing Tube Cap
54 Eyepiece Lens Lock Ring
55 Focusing Tube Set Screw
56 Mirror Mount
57 Scale Mirror
58 Right Front Mirror Spring †
59 Left Front Mirror Spring †
60 Side Front Mirror Spring †
†Not shown
61 Mirror Spring Screw
62 Mirror Mount Screw
63 Mirror Mount Cover
64 Mirror Mount Cover Screw
65 Vertical Scale Index Adjustment Screw
66 Vertical Scale Index Adjustment Screw Spring
67 Vertical Scale Index Adjustment Screw Plunger
68 Vertical Scale Index Adjustment Screw
69 Vertical Scale Index Adjustment Screw Nut
70 Light Gathering Lens
71 Tangent Screw Arm Nut
72 Tangent Screw Arm Retaining Ring
73 Tangent Screw Arm
74 Tension Plate
75 Tangent Adjusting Screw
76 Tangent Screw Arm Screw
77 Scale Mount
78 Scale
79 Scale Plate
80 Plate to Scale Mount Screw
81 Scale Mount to Barrel Pin
82 Scale Mount Washer
83 Scale Mount Nut
84 Button Plug
311 Trough Compass Base
312 Tr. Comp. Base Screw
313 Tr. Comp. Cover
314 Tr. Comp. Cover Glass
315 Tr. Comp. Cover Screw
316 Tr. Comp. Needle
317 Tr. Comp. Needle Cap
318 Tr. Comp. Needle Balance Clip
319 Tr. Comp. Needle Spacer
320 Tr. Comp. Needle Spacer Screw
321 Tr. Comp. Needle Lifter
322 Tr. Comp. Needle Lifter Screw
323 Tr. Comp. Needle Cam (Not Shown)
324 Tr. Comp. Needle Lifter Lever
325 Tr. Comp. Needle Lifter Lever Washer
326 Tr. Comp. Needle Lifter Lever Screw
327 Tr. Comp. Needle Lifter Lever Stop Screw
328 Circular Level
329 Circular Level Screw
337 Base Plate Knob

K&E PARAGON®—SELF-INDEXING
EXPEDITION ALIDADE

5231-500 Telescope Barrel & Axle
501 Telescope Front Sight
502 Telescope Cap
503 Telescope Sunshade (Not Shown)
504 Objective Lens & Mount
505 Pinion Saddle to Barrel Screw
506 Body Tube
507 Body Tube Set Screw
508 Telescope Draw Tube
509 Telescope Focusing Lens
510 Telescope Focusing Lens Lock Ring
511 Telescope Pinion Rack
512 Telescope Focusing Pinion Rack Screw (Not Shown)
513 Reticule & Mount
514 Reticule Mount Set Screw
515 Telescope Pinion Mount
516 Telescope Focusing Pinion
517 Telescope Focusing Pinion Head
518 Telescope Focusing Pinion Tension Ring
519 Telescope Focusing Knob Set Screw
520 Telescope Focusing Pinion Mount Set Screw
521 Eyepiece Sleeve
522 Eyepiece Mount
523 Eye Lens
524 Eye Lens Spacing Ring
525 Eyepiece Field Lens
526 Eyepiece Field Lens Spacing Ring
527 Eyepiece Field Lens Lock Ring
528 Eyepiece Cam Screw
529 Eyepiece Focusing Ring
530 Eyepiece Focusing Ring Lock Screw
531 Eyepiece Focusing Diopter Scale
532 Eyepiece Focusing Diopter Scale Screw
533 Holder With Prism Mount
534 Eyepiece Cap

When ordering parts, state Serial No. of instrument.

MAINTENANCE, LUBRICATION AND DISASSEMBLY OF ALIDADES

76 0020 & 76 0030

In the maintenance of alidades, the following are accomplished as described for transits on pages 26, 27, 30, 31:

1. Precautions for taking the instrument apart.
2. To remove the reticule.
3. Preparation for Arctic temperatures.

The alidade is lubricated in the same manner as a transit except that only the following points need be lubricated:

1. Telescope axle bearings.
2. Clamp springs and plungers of both tangent motions.
3. Threads of clamp screw and the two tangent screws.

TO DISASSEMBLE THE ALIDADE

1. Remove tangent screws, unscrew spring boxes and remove springs and plungers. Note where each belongs.
2. Unscrew trunnion cap screws and remove caps.
3. Lift out telescope.
4. Unscrew clamp screw.

All surfaces that need to be cleaned and lubricated are now exposed. Re-assemble the instrument in reverse order. Make sure that the telescope bearing caps are replaced according to the matching numbers.

ALIDADE ADJUSTMENTS

First read the general directions under "Adjustments" on pages 31-33.

The circular levels on K&E alidades require no adjustment.

ADJUSTMENT OF CONVENTIONAL ALIDADES

The Cross Line Reticule

1. ***Object.*** To rotate the reticule until the vertical cross line is in a plane perpendicular to the elevation axis.

Proceed as described under Transit Adjustment 3 on page 34.

2. ***Object.*** To make the line of sight coincide with the axis of the collars.

Test. Release the telescope, so that it may be rotated, by loosening the telescope clamp ring (398) that surrounds the telescope at the forward end of the supporting sleeve. Make sure that after it is released the telescope is turned clockwise, when viewed from the objective end, against the stop.

Aim at a leveling rod or other vertical graduated scale 100 feet or more distant. Center the striding level bubble with the tangent screw and read the rod.

Rotate the telescope 180°, center the bubble and read the rod. The reading should be the same.

Adjustment. Loosen a side reticule adjusting screw. Then, by turning the vertical reticule adjusting screws by small increments, bring the line of sight to a point half way between the two readings. Tighten the side screw.

Rotate the telescope 90°, center the bubble, and adjust the other cross line to the same reading.

Each adjustment may interfere with the other, so that checks must be made back and forth until both lines point at the mid-point reading when the bubble is centered.

The Striding Level

3. ***Object.*** To make the striding bubble

center when the axis of the collars is horizontal.

Test. Center the bubble with the tangent screw. Reverse the striding level. The bubble should center.

Adjustment. Move the bubble half way toward the center with the tangent screw. Center it with the opposing nuts at one end of the level tube.

The Vernier Control Level

4. ***Object.*** To make the vernier control level bubble center when the line of sight is horizontal, and the vernier reads 30°.

Test. Center the striding level bubble with the tangent screw.

Set the vernier at 30° with its tangent screw. The bubble should center.

Adjustment. Center the bubble with the capstan screw or, on some types, with the opposed nuts, at the end of the bubble tube.

FIELD ADJUSTMENT OF SELF-INDEXING ALIDADES
76 0000 & 76 0010

1. ***Object.*** To make the zenith distance read 90° when the line of sight is horizontal.

Two methods are recommended, the collimator method and the peg method. The collimator method is the better of the two but it requires a level instrument in good adjustment.

The Collimator Method. Set up the alidade on a plane table and set up a level instrument in good adjustment as close to it as possible. Choose a location so that a well illuminated background is behind the level. Regulate the height of the level so that the two instruments are at very nearly the same elevation. Focus the level on some point 800 feet or more distant.

Without changing the focus, aim it approximately at the center of the plane table and carefully center the spirit level.

Stand on the opposite side of the plane table from the level and move the eye until a round spot of light is seen through the level. Place the alidade telescope barrel on the line established by the spot of light and pointed toward the level telescope. The spot of light should appear in the alidade telescope. It will look like a very hazy white circle if the alidade is not in focus or, if the alidade is nearly in focus, the background *seen through the level* may appear. Regulate the focus until the cross lines of the level are seen, and carefully focus on them. If the two instruments are properly in line, the field of view through the level will be a clear-cut circle approximately in the center of the field of view of the alidade.

Test. Bring the central horizontal cross line of the alidade exactly on the central horizontal cross line of the level. Due to the collimator action of the level, the line of sight of the alidade will be parallel to that of the level even if the two instruments are not exactly alined with each other. Accordingly, the line of sight of the alidade will be exactly level and the reading should be exactly 90°.

Adjustment. To adjust the reading, loosen the capstan lock nut just to the right of the tangent screw mechanism at the rear of the instrument and regulate the capstan screw.

The Peg Method. Select two supports for the alidade about 200 feet apart and at nearly the same elevation. Two plane tables are excellent. Construct a small target that will stand on the plane table at exactly the same height as the center of the friction adjusting screw on the left end of the telescope axle.

Test. Level the instrument on one support and place the target on the other. Aim at the

target and record the zenith distance reading. Mark the horizontal position of the center of the instrument and the position of the target and interchange them. Aim at the target with this arrangement and record the second zenith distance. The average of the two zenith distances should be exactly 90°.

Adjustment. To adjust the reading, loosen the capstan lock nut just to the right of the tangent screw mechanism at the rear of the instrument and regulate the capstan screw. If the average of the readings is not 90°, change the reading at the second position in a direction toward 90° by an amount equal to the error of the average.

	Example 1	Example 2
First reading	88° 20′	92° 32′
Second reading	91° 48′	87° 26′
Sum	180° 08′	179° 58′
Average	90° 04′	89° 59′
	Error 04′	*Error 01′*
	2nd Reading 91° 48′	*2nd Reading 87° 26′*
Set at	91° 44′	87° 27′

DISASSEMBLY AND SHOP ADJUSTMENTS—SELF-INDEXING ALIDADES

76 0000 & 76 0010

DISASSEMBLY

To Remove the Blade. Unscrew the four screws underneath the blade that are threaded upward into the pedestal.

Object. To align the line of sight with the edge of the blade. This adjustment is not necessary unless the blade has been removed or when

two or more alidades are to be used on the same manuscript or map.

Test. Place the instrument on a plane table and carefully level the plane table. Make up a target with two short vertical lines 1½ inch apart, designed so that the right-hand line can be seen by the naked eye and the other through the telescope. Mount the target so that it is nearly in line with the surface of the plane table and at least 25 feet distant. Aim the line of sight at the left-hand target. Eye along the right-hand edge of the blade. The right-hand target should be on line.

If this test is to be made several times, it is best to set up a permanent jig that will hold the blade in a definite position. A permanent mark can then be established on which the line of sight should fall.

Adjustment. Loosen the four screws underneath the blade that screw up into the pedestal. The holes in the blade are oversize so that the pedestal can be rotated through a small angle. Adjust as required and tighten the screws.

To Remove the Standards from the Pedestal. At the top of the pedestal is cemented a large rubber washer. Work this loose and move it down the pedestal. Four Allen-head screws will be exposed which thread upward into the base of the standards. Remove these screws.

To Remove the Telescope Eyepiece for Cleaning. Unscrew and remove the knurled-screw ring at the eyepiece end next to the telescope barrel. Rotate the eyepiece counterclockwise until a set screw can be seen in the side of the eyepiece sleeve. Remove this screw. This screw serves as a pawl which engages the spiral focusing groove. Slide out the assembly. In reassembly, this pawl must be engaged in the groove.

To Remove the Focusing Knob and Pinion. This is mounted on the top of the tele-

scope. Loosen the set screw on the right side of the focusing-knob-pinion housing. Pull out the knob. To replace the pinion, carefully push it into the housing, rotating the knob back and forth slightly so that the teeth of the pinion will engage in the rack. Hold the knob so that the set screw will engage in the hole. Tighten the set screw.

To Remove the Scale-Reading Eyepiece. This is the black knurled cylinder at the top of the left-hand standard. Loosen the set screws at the side of the eyepiece. Pull out the eyepiece.

THE OPTICAL SYSTEM

The adjustment of the optical system is a delicate and pains-taking operation. Since it requires the removal of certain cover plates which expose sensitive parts, it must be performed in a dust-free room. Under no circumstances should the main left-hand cover plate be removed. This exposes the pendulum mechanism. The pendulum mechanism cannot be disassembled or repaired except by a *specially trained* instrument repairman. The Keuffel & Esser Co. has instrument repairmen trained for this work at their main factory in Hoboken, N. J.

1. ***Object.*** To regulate the focus of the scale reading eyepiece so that, when the minute scale is in focus, the slope scales will also be in focus.

Adjustment. Focus the eyepiece on the minute scale by rotating the eyepiece in the usual way. Loosen the two set screws located one above the other on the side of the left-hand standard. Move the whole eyepiece mount up and down until the slope scales are in focus. Make sure that both the minute and the slope scales are in focus simultaneously. When they are properly focused, no parallax will appear when the eye is moved back and forth.

CAUTION

Before tightening the two set screws, move the telescope up or down until the index line on the elevation angle scale reads 90°. At this point the graduation mark at the 50 reading on the "V" scale should be centered between the paired index lines. The 100 graduation mark on the "H" scale should be directly under the horizontal index line. If this does not occur, rotate the scale reading eyepiece sleeve clockwise or counter-clockwise until this condition is met. Recheck the eyepiece for proper focus. Tighten the set screws.

2. ***Object.*** To make the index lines parallel to the slope-scale markings and to center them so that they extend across the markings.

Adjustment. Follow the same procedure as noted in the Caution portion above.

3. ***Object.*** To adjust the elevation angle scale so that it reads 90° when the telescope is level.

Adjustment. Place the alidade on an approximately horizontal surface. Aim the line of sight at a level collimator (a surveying level will serve).

Fine Adjustment. Some instruments are equipped with an opposed screw & lock nut located at the lower right end of the standard. In this case, loosen both capstan head lock nuts and regulate both screws simultaneously. If the instrument is not equipped as above, the adjusting screw will be at the objective end of the lower part of the standard. Loosen the lock nut and rotate the screw until the proper adjustment is made.

Coarse Adjustment. If the fine adjustment is not sufficient to eliminate the error, proceed as follows:

On the left-hand main cover plate is a small cover plate about ½ inch long which is held in place by a screw. Remove this plate. Five screws are underneath it. The three small screws push and the two large screws pull on the support of a small mirror. By tightening and loosening these screws, the required adjustment is made.

The two small screws on the right-hand side, when turned in opposite directions to each other, move the index line to the left or right, depending upon the sequence used in turning. The small left-hand screws, operated in conjunction with the larger left-hand center screw, move it up or down.

When the adjustment is completed, all screws should be firm.

4. ***Object.*** **A.** To regulate the apparent swing of the pendulum so that it gives the correct reading when the blade is tilted to any angle within the pendulum's range of correction.

B. To regulate the apparent length of the slope scale.

Preparation. Remove the spring and plunger that oppose the main tangent screw. To do this, unscrew the cap mounted on the standard in line with the tangent screw. A coin or screw driver may be used. A spring and plunger should come out with the cap. If they do not, turn the instrument objective end down and tip it until they come out.

Grind out the center of the blade of a small screw driver so that a V-shaped notch is formed which will fit the screws. Remove the six screws located around the perimeter of the cover plate on the right-hand standard. Lift off the plate.

Unscrew the large slope-friction adjusting screw at the right-hand end of the elevation axis. Remove this screw and with it both the rubber and brass washers. Lift off the tangent screw arm.

With a spanner wrench, unscrew and remove the lock ring and the washer which hold the scale mount.

Lift off the scale mount carefully. Note the pin which holds the mount in the proper position. The pin may come out with the scale mount, if it does not, let it remain. If it does come out, in assembly the pin must be replaced in the same hole.

A small lever will be exposed. This lever is actuated either by two opposed screws or by a single screw and an opposed spring and plunger. Remove the spring and plunger or the opposing screw. This is done by loosening the capstan head lock nut and unscrewing the Allen-head screw located at the base of the standard on the eyepiece side.

In the same manner, back off the other screw located at the base of the standards on the objective side. Remove the two screws that hold a small plate which retains the lever.

The lever is part of and at the end of a horizontal cylinder which is a mount for two small lenses. Carefully extract the lens mount. Loosen two set screws in the lens mount. One is threaded into the side of the cylinder and the other is parallel to it and threaded into the lower end of the lever. Tighten the set screws until they provide a slight friction which will tend to hold in position the two lens cells within the cylinder.

Push the lens cell nearest the arc about $\frac{1}{32}$ inch towards the arc.

Completely re-assemble all parts including the cover plate, tangent-screw and opposing-spring assembly.

Test. **A.** Aim the line of sight into a level collimator. A surveying level will serve. Note the reading. Adjust the support of the blade until the zenith distance reads approximately 25 minutes. Re-aim the line of sight at the colli-

mator. The zenith distance reading should be the same as before. If it is not, remove the cover plate & follow the adjustment procedure below.

Adjustment. Remove the cover plate, move the lens mount nearest the arc to the left if the angle reading is too large and vice-versa. Replace the cover plate. Check by tilting the blade about 25 minutes in the opposite direction.

***Test.* B.** With the tangent screw, aim the telescope so that the zero end of the scale coincides with a degree mark. The 60 minute mark should coincide with the next smaller degree mark.

Adjustment. Remove the cover screw at the right of the center in the base of the standards on the eyepiece side.

One small lens cell will be exposed which contains the lens to be adjusted. Around the cell is a groove. The cell can be moved left or right by engaging a small screw driver in the groove.

Move the cell to the left or right until the vernier is the correct length.

Note whether or not the focus of the scale is still clear when observed through the eyepiece. If any parallax exists, adjust the scale-reading eyepiece sleeve up or down until parallax is eliminated.

When these adjustments are complete, disassemble, remove the mount that contains the lens cells and tighten the set screws.

Reassemble all parts and recheck all adjustments. Particularly, check the adjustment of the scale reading eyepiece.

SHIPPING AN INSTRUMENT

To ship a transit, first screw it to the base plate. Place the instrument in the case, carefully following the instructions on page 21. Tighten the washers and thumb screws, making sure even pressure is applied on both sides. Place tight wads of newspaper in position so that, if the clamps or leveling screws should slip, the instrument will not come in contact with the case.

Place the case in a strong box about 2 inches larger than the instrument case all around. Pack closely wadded newspaper or other shock absorbing material in the space.

To ship a level or alidade, the above instructions should be modified in accordance with the type of instrument.

Unless the instrument is carefully described in the correspondence and the serial number given, it is sometimes difficult to identify its ownership. A good plan is to tie a tag to the instrument itself with the serial number of the instrument and the owner's name written on it.

THREE-WIRE LEVELING

For fast, accurate, self-checking benchmark leveling, the three-wire method is outstanding. Both U. S. Geological Survey and the U. S. Coast and Geodetic Survey have found it to be the most economical and the most accurate method yet developed. In spite of this fact, the three-wire method is unfamiliar to many engineers.

K&E leveling equipment is designed so that this method can be applied to the best advantage whenever desired.

Method. The three-wire method can be applied whenever the reticle of the level has stadia lines. The rod is read at each of the three lines and the average is used for the final result. The bubble is centered before each reading. The half-stadia intervals are compared to check for blunders. Example:

	Reading	
Upper Wire	8.798	2.235 Upper Intercept
Middle Wire	6.563	2.231 Lower Intercept
Lower Wire	4.332	
Sum	19.693	
Average	6.564	

The final rod reading is 6.564 feet. The upper and lower intercepts differ by only 0.004 foot, which is a normal accidental error, so that it is evident that no blunder has been made.

Theory.

1. Tests have shown that the levelman can read the rod more accurately than he can set a target.

2. The three readings can be made very quickly as the adjustment of the bubble between readings never requires more than a slight movement.

3. The note-keeper can check the intercepts more quickly than the reading can be checked by the rodman.

4. The accuracy is as great as if three lines of levels had been run and the results averaged.

5. Since the stadia intercept is available, the length of each sight is known and the total length of run between benchmarks can be computed. This can be used to compute the accuracy of the work and to adjust a level net.

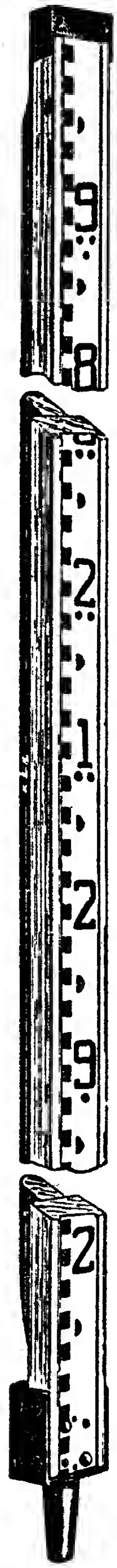
6. The unbalance between the horizontal lengths of the foresight and the backsight at each instrument position is known at once.

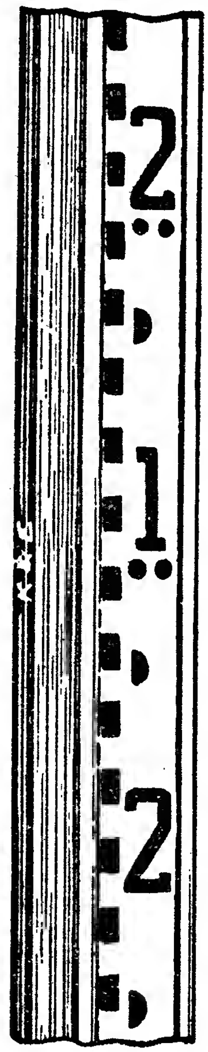
7. When the instrumental error per unit distance is determined by the peg method, the effect of the error can be eliminated, since the residual unbalance between the foresights and the backsights can be computed.

K&E Equipment. To facilitate the three-wire method, K&E furnishes reticules that have stub-stadia lines that are spaced so that the stadia intercept is 0.3 foot at 100 feet, instead of 1.0 foot at 100 feet. The stub-stadia lines are short cross lines that cannot be mistaken for the long central line used for ordinary leveling. Reducing the size of the stadia intercept has two advantages. The lines are brought nearer to the best part of the optics, and there is less chance for the lines of sight to fall above or below the rod when there is considerable difference in height between the instrument and the rod.

The Zeiss Ni2 Self-Leveling Level (K&E No. 75 0020) is exceptionally well adapted to three-wire leveling. It is extremely accurate. No releveling is required between the readings of the three wires. It is regularly equipped with a glass reticule with cross- and stub-stadia lines having a stadia intercept of 0.3 per 100.

The K&E Yard Rod. This rod, No. 81 0537, is designed for precise benchmark leveling by the three-wire method. It combines all of the features required in a precise rod in a light, easily handled piece of equipment. It is shown in the illustration and described in detail in later paragraphs. Its chief feature is that it





Front

Back showing
circular level
and thermometer

LOVAR® Precise Rod No. 81 0537

is engine divided on LO-VAR® steel to hundredths of a **yard.** This makes the divisions more clearly visible at greater distances and the accuracy of the readings is increased.

Theory. It is well known that readings on a Philadelphia rod can seldom be repeated more accurately than to 2 or 3 thousandths of a foot. It follows that a rod cannot be read at usual sight distances to better than the nearest thousandth of a yard. On the yard rod, thousandths of a yard are easily read by estimation.

The size of a hundredth of a yard division corresponds closely to the size of the divisions used on the rods of the U. S. Geological Survey and the U. S. Coast and Geodetic Survey. For first order leveling, these agencies use rods divided in centimeters. A hundredth of a yard is very nearly a centimeter.

Advantage. The obvious advantage of the yard rod for three-wire leveling is that **the sum of the three readings gives the rod reading in feet.** Moreover, when the 0.3 per 100 stadia intercept is used, the length of a sight in feet is found by multiplying the total stadia intercept by 1000. Example:

	Reading	
Upper Wire	2.879	
Middle Wire	2.802	
Lower Wire	2.724	
Sum	8.405	Rod reading in feet
Difference Upper & Lower Wire	0.155	
Length of sight	155 feet	

Description of Yard Rod. The Yard Rod No. 81 0537 consists of a T-section mahogany staff 12 feet long with a face 1½ in. wide. It supports, in recessed guides, the LO-VAR® steel engine divided ribbon, graduated to yards, 10ths and 100ths of yards. The lower end of the ribbon is securely attached to the hardened

steel shoe and the upper end is held at an established tension by a strong spring. The pattern of the markings is shown in the illustration.

The rod may be supplied with a circular rod level No. 81 0550 and also a Precise Rod Thermometer No. 81 0545 which can be mounted in a hole through the rod so that its bulb is in contact with the back of the ribbon.

Two-Rod Method. In order to obtain the best speed in precise leveling, two rods should be used. When the observations are completed at any instrument set-up, the rods and the instrument are moved forward simultaneously. Half way between benchmarks, the rods should be interchanged to eliminate the effect of any possible index error. This method should always be used with the Self-Leveling Level in order to take full advantage of the great speed possible with this instrument.

K&E is prepared to furnish these rods in pairs in a suitable wooden carrying case, which has space provided for the storage of two rod levels and two thermometers.

Suggested Form for Field Notes. K&E has received many requests for a suggested form for field notes for three-wire leveling. Three such forms are appended. The first form can be used with an ordinary rod graduated in feet. It shows all of the arithmetic checks that are available when three-wire leveling is used. The second form is similar but applies to the yard rod. The third is a short form for use with the yard rod. Explanations are given with each form. K&E Transit Book No. 82 0014 or Loose Leaves No. 82 0267 are easily adapted for recording these notes.

Suggested Form of Notes for Philadelphia Rod

Rod	Stad.	Check	−Rod	Stad.	Check	Elev.	Sta.	Stad.
8.266(1)			3.491			98.461	BM 29	
	161(4)			171				
8.105(2)		−.0013(6)	3.320		+.0010	+8.104		+326
	165(5)			168				
7.940(3)		8.1037(7)	3.152		3.3210	106.565	HI	+326
24.311(8)		8.1037(10)	9.963		3.3210	−3.321		−339
0.326(9)	326(11)		0.339	339		103.244	TP 1	− 13(12)
6.574			4.623					
	216			204				
6.358		−.0003	4.419		+.0013	+6.358		+433
	217			200				
6.141		6.3577	4.219		4.4203	109.602	HI	+420
19.073		6.3577	13.261		4.4203	−4.420		−404
.433	433		.404	404		105.182	TP 2	+ 16
6.203			2.819					
	182			188				
6.021		+.0013	2.631		+.0010	+6.022		+360
	178			185				
5.843		6.0223	2.446		2.6320	111.204	HI	+376
18.067		6.0223	7.896		2.6320	−2.632		−373
.360	360		.373	373		108.572	BM 30	+ 3
Sums	1.119	20.4837		1.116	10.3733			

Explanation. This form of notes is arranged to fit a standard field note book. There are six columns for the left-hand page and three columns for the right-hand page. The standard twenty-five lines are used, five lines for each instrument position.

The first three columns apply to the backsights, the next three apply to the foresights and the right-hand page is used to carry the elevations and the cumulative unbalance of the stadia intercepts.

(1), (2), (3) are wire readings.

(4)=(1)−(2), (5)=(2)−(3), (6)=(4−5)÷3, (7)=(2)+(6)
(8)=(1)+(2)+(3), (9)=(1)−(3), (10)=(8)÷3, (11)=(4)+(5)
(12) is the cumulative unbalance of the stadia intercepts.

Checks. (7) must equal (10) and (9) must equal (11).

Sums. The sums at the bottom of the page are respectively the sum of the lengths of the foresights (in stadia intercepts), the sum of the foresights, and corresponding values for the backsights. When properly combined, they are used to check the values for the final benchmark, viz:

	Elev.	Stad.
	20.4837	1.119
	− 10.3733	−1.116
	+ 10.1104	+ .003
BM 29	98.4610	0
BM 30	108.5714	+ .003

Suggested Form of Notes for Yard Rod

+ Rod	Stad.	Check	− Rod	Stad.	Check	Elev.	Sta.	Stad.
3.897(1)			0.734			206.481	BM 61	0
	72(4)			76				
3.825(2)		11.475(6)	0.658		1.974	+11.473		+146
	74(5)			77				
3.751(3)		−2(7)	0.581		−1	217.954	HI	+146
11.473(8)		11.473(9)	1.973		1.973	−1.973		−153
.146(10)	146(11)		.153	153		215.981	TP 1	− 7(12)
2.694			1.248					
	63			62				
2.631		7.893	1.186		3.558	+7.894		+125
	62			61				
2.569		+1	1.125		+1	223.875	HI	+118
7.894		7.894	3.559		3.559	−3.559		−123
.125	125		.123	123		220.316	TP 2	− 5
3.174			2.648					
	55			60				
3.119		9.357	2.588		7.764	+9.360		+107
	52			60				
3.067		+3	2.528		+0	229.676	HI	+102
9.360		9.360	7.764		7.764	−7.764		−120
.107	107		.120	120		221.912	BM 62	− 18
28.727	378		13.296	396				

Explanation. This form of notes is also arranged to fit a standard field notebook, with six columns for the left-hand page and three columns for the right. Again the standard twenty-five lines are used, five lines for each instrument position.

(1), (2), (3) are wire readings.

(4) = (1) − (2), (5) = (2) − (3), (6) = three times (2), (7) = (4) − (5)
(8) = (1) + (2) + (3), (9) = (6) + (7), (10) = (1) − (3), (11) = (4) + (5)
(12) is the cumulative unbalance of the stadia intercepts.

Checks. (8) must equal (9) and (10) must equal (11).

Sums. The sum 28.727 should be computed by adding all the plus rod readings and the sum 378 by adding all the half stadia intercepts. Similarly for 13.296 and 396. When properly combined, they are used to check the values for the final benchmark, viz:

	Elev.	Stad.
	28.727	378
	−13.296	−396
	15.431	− 18
BM 61	206.481	0
BM 62	221.912	− 18

Short Form of Field Notes for Yard Rod

+ Rod	Stad.	− Rod	Stad.	Stad.	Elev.	Sta.
3.897(1)		0.734			206.481	BM 61
	72(4)		76			
3.825(2)		0.658				
	74(5)		77			
3.751(3)	146(7)	0.581	153(8)			
11.473(6)		1.973(9)		− 7(10)	+9.500(11)	
2.694		1.248			215.981	TP 1
	63		62			
2.631		1.186				
	62		61			
2.569	125	1.125	123			
7.894		3.559		+ 2	+4.335	
3.174		2.648		− 5	220.316	TP 2
	55		60			
3.119		2.588				
	52		60			
3.067	107	2.528	120			
9.360		7.764		−13	+1.596	
				−18	221.912	BM 62
28.727	378	13.296	396			

Explanation. In this short form of field notes only five columns are used on the left-hand page of the field notebook, and two on the right.

(1), (2), (3) are wire readings.
(4) = (1) − (2), (5) = (2) − (3), (6) = (1) + (2) + (3), (7) = (4) + (5), (10) = (7) − (8), (11) = (6) − (9)

Sums. The sum 28.727 should be computed by adding all the rod readings and the sum 378 by adding all the half stadia intercepts. Similarly for 13.296 and 396. When properly combined, they are used to check the values for the final benchmark, viz:

	Elev.	Stad.
	28.727	378
	−13.296	−396
	+15.431	− 18
BM 61	206.481	0
BM 62	221.912	− 18

STADIA MEASUREMENTS

Purpose. Stadia provides a method of measuring distances and differences in elevation by merely sighting a rod. It is very rapid, and the accuracy is better than is necessary for even large scale mapping. Stadia is always used for measurements with a plane table and it is nearly always used for locating topography with a transit. Stadia is often employed exclusively for complete traverses as well as for ties to other control.

Theory. Two supplementary horizontal lines called stadia lines are placed at equal distances above and below the central horizontal cross line of the instrument. When a graduated rod is sighted, the length of rod between the stadia lines can be observed. This is called the stadia intercept, S.

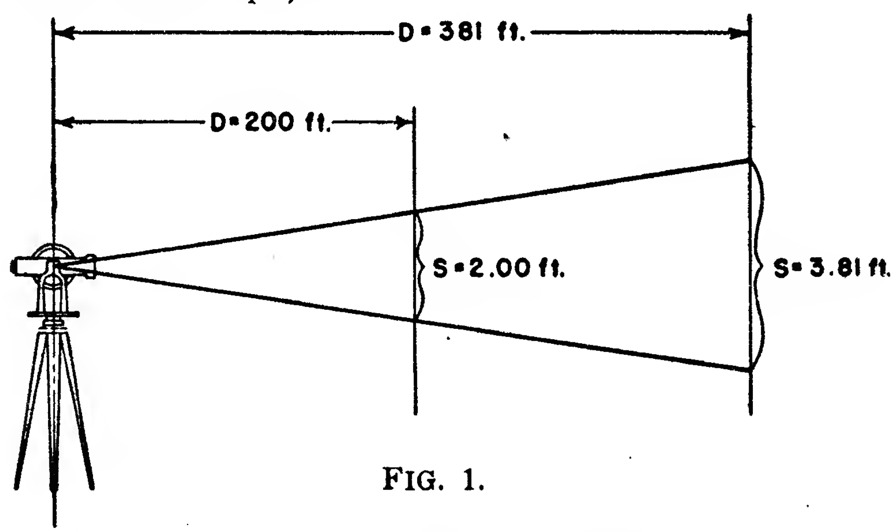


FIG. 1.

In modern K&E internal focusing instruments the distance between the stadia lines is such that, when the telescope is horizontal and the rod is vertical, the distance D from the center of the instrument to the rod is equal to **100 times the stadia intercept.** (Fig. 1), i. e.,

$$D = 100S \qquad (1)$$

In Level No. 75 0020, D is equal to 333 times the stadia intercept. No. 75 0000 is furnished with this intercept, when so ordered.

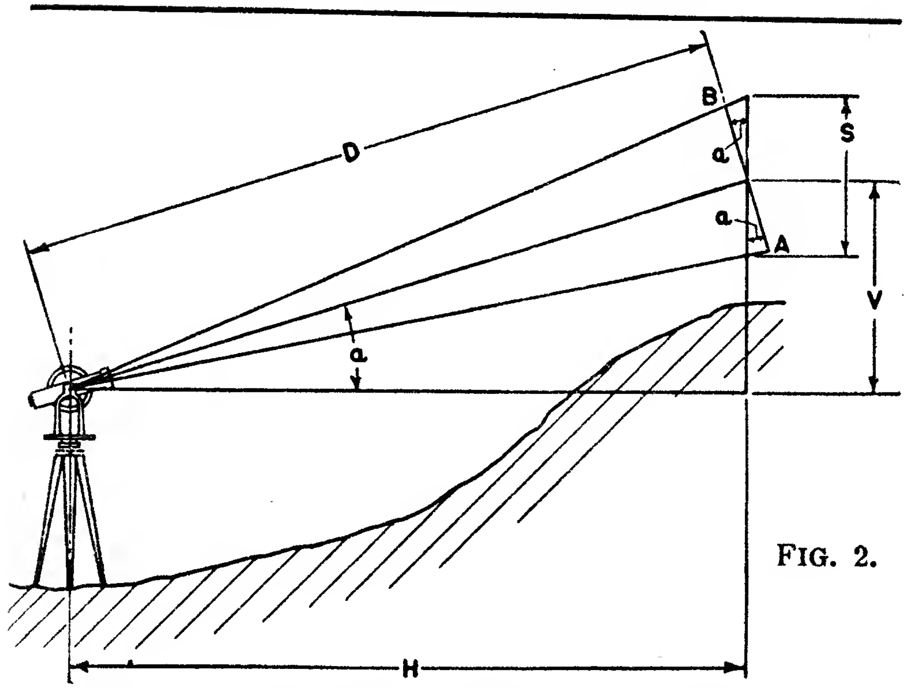


FIG. 2.

Inclined Sights. When the sight is inclined as in Fig. 2, the stadia intercept S must be multiplied by the cosine of the vertical angle a to obtain AB perpendicular to D.

From (1) $\quad D = 100AB$

Therefore $\quad D = 100S \cos a \qquad (2)$

and $\quad H = D \cos a = S\,(100 \cos^2 a) \qquad (3)$

$\quad V = D \sin a = S\,(100 \sin a \cos a) \qquad (4)$

Stadia Computing Devices. Various devices are used to solve these formulas. Three are described below.

Stadia Tables. Stadia tables list the values in the parentheses in eqs. (3) and (4) for various values of a. Using a, the proper values are found in the table and multiplied by S to obtain the values of H and V. Some tables list corrections which, when multiplied by S and subtracted from $100S$, give values of H.

The stadia tables in this booklet (Tables A and B) give very accurate results and require only one opening of the book. They extend to vertical angles up to 10°. Larger vertical angles are so seldom encountered that reductions can be made for them directly from the formulas without loss of time.

Stadia Slide Rules. A well made stadia slide rule will give results which are more

accurate than stadia observations. The 10-inch K&E Kissam Stadia Slide Rule No. 68 1486 is more accurate than a stadia traverse in which the foresights and backsights have been averaged. Except for very unusual values, this rule gives H. V. and horizontal corrections, each with the position of the decimal point. The values never run off the scale. When tables are used the necessary multiplications alone require an equal number of settings. If none of these devices are available, an ordinary slide rule may be used although it lengthens the computation.

Stadia Circle or Arc. All K&E Plane Table Alidades have two special scales which automatically give the values found in stadia tables. K&E Transits may be so equipped. The values obtained must be multiplied by *S*. Since the spacing of the graduations is irregular, no vernier can be used. They are less accurate than the tables or the stadia slide rules and they are not as fast as the slide rules. Nevertheless they are frequently used because of their convenience. To avoid minus readings, the readings for vertical heights have been arbitrarily increased by 50 on all K&E instruments. Thus, 50 must be subtracted from each reading to obtain the true value. On K&E conventional alidades, 30° has been added to vertical angle readings. Thus, 30° must be subtracted to obtain the vertical angle. On K&E Self-Indexing Alidades, the vertical angle readings have been replaced by zenith distance readings. The zenith distance readings must be subtracted from 90° to obtain vertical angles.

Example	Zenith Distance	Corresponding Vertical Angle
	68	22
	108	– 18

Rods Used. Ordinary self-reading leveling rods with targets can be used up to 800 feet. Special stadia rods with graduations that are more easily read are used for longer distances.

Point Sighted on Rod. The difference in elevation V that is obtained by stadia, extends from the center of the instrument and the point sighted on the rod. To simplify the corrections necessary to obtain ground elevations, it is best to sight at a target set at the *h. i.* which is the height of the instrument center above the station over which the instrument is set up. V then equals the difference between the two ground elevations. Often a certain mark (usually the 5 ft. mark) is always sighted throughout the survey. V is then the vertical height from a point 5 ft. below the instrument center.

When differences in elevation are small, horizontal observations are used. Distances can be computed mentally from the stadia intercepts and elevations are handled as in leveling.

A Stadia Observation. As a rule, a stadia observation is performed by the following steps:

1. The cross lines are brought on the target at the *h. i.* or on the five foot mark, or the telescope is leveled, depending on the method in use.

2. The lower stadia line is then immediately placed on the nearest foot mark and the stadia intercept is obtained by subtracting the lower line reading from the upper line reading.

3. The telescope is returned to the original position and the rodman is started off to the next point.

4. The instrument readings are taken.

Observations with the Stadia Arc. To obtain better accuracy with a stadia arc, many engineers prefer to use a slightly different procedure after completing Steps 1 and 2 above. For Step 3 the telescope is changed in elevation just enough to cause the nearest graduation of the vertical stadia arc to coincide exactly with

the index. The position of the central cross line on the rod is then recorded. The difference in elevation, from the ground at the instrument to the ground at the rod, is then computed thus:

$$\text{h.i.} + \text{V} - \text{Rod Reading}$$

The Accuracy of Stadia Measurements. A single stadia observation has an accuracy of about 1/300 in distance and about 0.06 feet in elevation per hundred feet of length. A stadia traverse in which the intercepts and the vertical angles are observed in both directions along each course has an accuracy of about 1/500 and an elevation closure of about 0.8 feet $\times \sqrt{\text{miles}}$. Under unusual conditions it may be worth while to introduce special procedures to obtain high accuracy. The instruments must be calibrated very carefully, no approximation can be used in computation, each observation must be repeated many times, and refraction must be carefully avoided. With similar care accuracies as high as 1/2000 have been recorded.

Calibration of a Stadia Telescope. The formula for internal focusing instruments, $D = 100\,S$, changes slightly with changing focus and varies slightly from instrument to instrument. These variations are negligible except for very accurate measurements. For such determinations a correction curve should be constructed for the instrument to be used by measuring exact stadia intercepts at various known distances. The following distances are recommended: 25, 50, 100, 200, 400, 800, 1600 feet. Plot the curve on semi-logarithmic graph paper.

Formulas for External Focusing Instruments. On external focusing instruments, the distance X (Fig. 3), which is proportional

to the stadia intercepts, is measured from the exterior principal focus of the lens. To obtain a value for D the distances f and c must be added. Their sum (and hence the total correction) is about one foot.

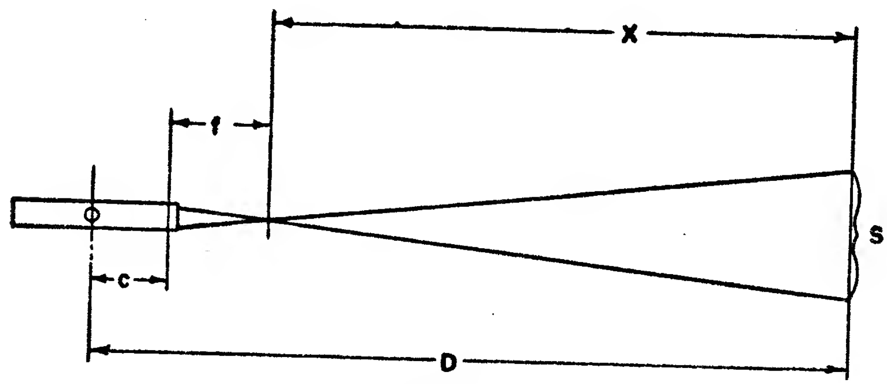


FIG. 3.

The resulting formulas are therefore:

$$D = 100\,S + 1 \qquad (5)$$
$$H = 100\,S \cos^2 a + \cos a \qquad (6)$$
$$V = 100\,S \cos a \sin a + \sin a \qquad (7)$$

Since a is usually less than 10 deg., multiplying the last term in eq. (6) and in eq. (7) by $\cos a$ will not appreciably change the values of H and V. These equations can therefore be written:

$$H = (S + .01)\,100 \cos^2 a \qquad (8)$$
$$V = (S + .01)\,100 \sin a \cos a \qquad (9)$$

Accordingly, all stadia computing devices can be used with external focusing instruments by substituting for S the value $S + .01$.

FORMULAS TO USE WITH VERTICAL ANGLES GREATER THAN 10°

	Internal Focusing	External Focusing
Hor. Dist.	$100\,S \cos^2 a$	$100\,(S + 0.01) \cos^2 a$
Vert. Ht.	$100\,S \sin a \cos a$	$100\,(S + 0.01) \sin a \cos a$

Where: S = stadia intercept; a = vertical angle

TABLE A

HORIZONTAL CORRECTIONS FOR STADIA INTERCEPT 1.00 FT.

Vert. Angle	Hor. Cor. for 1.00 ft.	Vert. Angle	Hor. Cor. for 1.00 ft.	Vert. Angle	Hor. Cor. for 1.00 ft.
0°00′		5°36′		8°02′	
	0.0 ft.		1.0 ft.		2.0 ft.
1°17′		5°53′		8°14′	
	0.1 ft.		1.1 ft.		2.1 ft.
2°13′		6°09′		8°26′	
	0.2 ft.		1.2 ft.		2.2 ft.
2°52′		6°25′		8°38′	
	0.3 ft.		1.3 ft.		2.3 ft.
3°23′		6°40′		8°49′	
	0.4 ft.		1.4 ft.		2.4 ft.
3°51′		6°55′		9°00′	
	0.5 ft.		1.5 ft.		2.5 ft.
4°15′		7°09′		9°11′	
	0.6 ft.		1.6 ft.		2.6 ft.
4°37′		7°23′		9°22′	
	0.7 ft.		1.7 ft.		2.7 ft.
4°58′		7°36′		9°33′	
	0.8 ft.		1.8 ft.		2.8 ft.
5°17′		7°49′		9°43′	
	0.9 ft.		1.9 ft.		2.9 ft.
5°36′		8°02′		9°53′	
					3.0 ft.
				10°03′	

Results from Table A are correct to the nearest foot at 1000 feet and to the nearest 1/10 foot at 100 feet, etc.

With a slide rule, multiply the stadia intercept by the tabular value and subtract the product from the horizontal distance.

Example. Vertical angle, 4°22′; stadia intercept, 3.58 ft.

Corrected Hor. Dist. =

$$358 - (3.58 \times 0.6) = 356 \text{ ft.}$$

Table B gives the vertical heights for a stadia intercept of 1.00 ft. With a slide rule, multiply the stadia intercept by the tabular value.

Example. Vertical angle, 4°22′; stadia intercept, 3.58 ft.

Vertical Height = $3.58 \times 7.59 = 27.2$ ft.

TABLE B

VERTICAL HEIGHTS FOR STADIA INTERCEPT 1.00′

Min.	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°
0	0.00	1.74	3.49	5.23	6.96	8.68	10.40	12.10	13.78	15.45
2	0.06	1.80	3.55	5.28	7.02	8.74	10.45	12.15	13.84	15.51
4	0.12	1.86	3.60	5.34	7.07	8.80	10.51	12.21	13.89	15.56
6	0.17	1.92	3.66	5.40	7.13	8.85	10.57	12.27	13.95	15.62
8	0.23	1.98	3.72	5.46	7.19	8.91	10.62	12.32	14.01	15.67
10	0.29	2.04	3.78	5.52	7.25	8.97	10.68	12.38	14.06	15.73
12	0.35	2.09	3.84	5.57	7.30	9.03	10.74	12.43	14.12	15.78
14	0.41	2.15	3.89	5.63	7.36	9.08	10.79	12.49	14.17	15.84
16	0.47	2.21	3.95	5.69	7.42	9.14	10.85	12.55	14.23	15.89
18	0.52	2.27	4.01	5.75	7.48	9.20	10.91	12.60	14.28	15.95
20	0.58	2.33	4.07	5.80	7.53	9.25	10.96	12.66	14.34	16.00
22	0.64	2.38	4.13	5.86	7.59	9.31	11.02	12.72	14.40	16.06
24	0.70	2.44	4.18	5.92	7.65	9.37	11.08	12.77	14.45	16.11
26	0.76	2.50	4.24	5.98	7.71	9.43	11.13	12.83	14.51	16.17
28	0.81	2.56	4.30	6.04	7.76	9.48	11.19	12.88	14.56	16.22
30	0.87	2.62	4.36	6.09	7.82	9.54	11.25	12.94	14.62	16.28
32	0.93	2.67	4.42	6.15	7.88	9.60	11.30	13.00	14.67	16.33
34	0.99	2.73	4.47	6.21	7.94	9.65	11.36	13.05	14.73	16.39
36	1.05	2.79	4.53	6.27	7.99	9.71	11.42	13.11	14.79	16.44
38	1.11	2.85	4.59	6.32	8.05	9.77	11.47	13.17	14.84	16.50
40	1.16	2.91	4.65	6.38	8.11	9.83	11.53	13.22	14.90	16.55
42	1.22	2.97	4.71	6.44	8.17	9.88	11.59	13.28	14.95	16.61
44	1.28	3.02	4.76	6.50	8.22	9.94	11.64	13.33	15.01	16.66
46	1.34	3.08	4.82	6.56	8.28	10.00	11.70	13.39	15.06	16.72
48	1.40	3.14	4.88	6.61	8.34	10.05	11.76	13.45	15.12	16.77
50	1.45	3.20	4.94	6.67	8.40	10.11	11.81	13.50	15.17	16.83
52	1.51	3.26	4.99	6.73	8.45	10.17	11.87	13.56	15.23	16.88
54	1.57	3.31	5.05	6.79	8.51	10.22	11.93	13.61	15.28	16.94
56	1.63	3.37	5.11	6.84	8.57	10.28	11.98	13.67	15.34	16.99
58	1.69	3.43	5.17	6.90	8.63	10.34	12.04	13.73	15.40	17.05
60	1.74	3.49	5.23	6.96	8.68	10.40	12.10	13.78	15.45	17.10

HOW TO SET OFF THE MAGNETIC DECLINATION

The magnetic declination is the angle measured from the true north to the direction of the compass needle. A 12° west declination is present when the needle points 12° west of true north. The declination is different in different localities, and in any locality it is continually changing. The U. S. Coast and Geodetic Survey publishes charts from which the declination can be estimated for any time or place in the United States.

When the compass circle is set in its normal position, the needle gives the magnetic bearing of the line of sight. This is shown in Fig. 1. with the instrument pointed to the true north. The compass circle can be rotated by turning the capstan head pinion (near the south or west mark) so that the needle will give the true bearing of the line of sight.

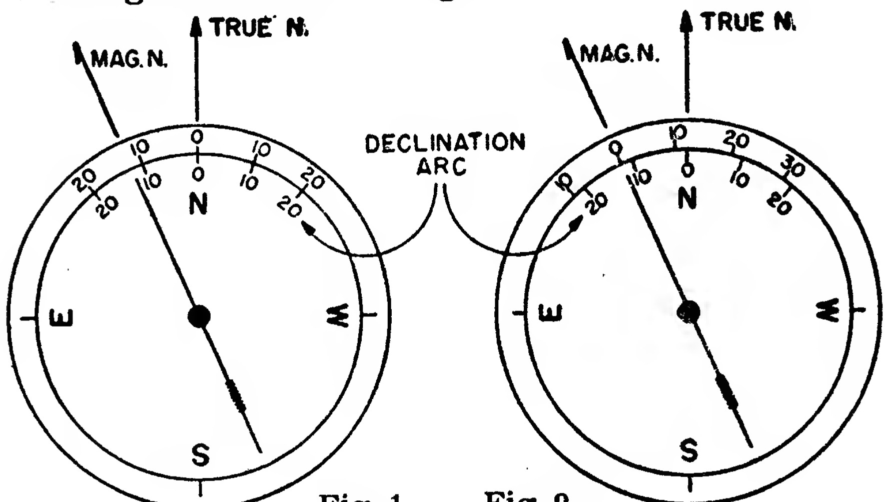


Fig. 1. Fig. 2.

The extent of rotation of the circle is measured *by the declination arc* in the base of the compass box next to the north part of the circle.

To set the circle for a declination of 12° west, turn the pinion clockwise and hence the circle counter-clockwise until the zero of the circle coincides with 12° to the left of N on the declination arc. The result is shown in Fig. 2. The instrument will now read true bearings for all points of the compass. The procedure is the same in the southern hemisphere.

UNITS OF MEASURE

LENGTH

U. S. SYSTEM

1 mile (mi)	= 5280	feet
1 chain (ch)	= 66	feet
1 rod (rd)	= 16.5	feet
1 yard (yd)	= 3	feet
1 foot (ft)	= 12	inches (in)
1 nautical mile	= 6076.1155—	feet
1 fathom (fm)	= 6	feet

METRIC SYSTEM

1 kilometer (km)	= 1000 meters
1 meter (m)	= 1000 millimeters
1 millimeter (mm)	= 1000 microns
1 micron (μ)	= 1000 millimicrons
1 millimicron (mμ)	= 1000 millionth microns (μμ)
1 meter	= 10 decimeters
1 decimeter (dm)	= 10 centimeters (cm)
1 millimicron	= 10 angstroms (A)

CONVERSION 1959-FOOT SYSTEM AND METRIC SYSTEM

1 kilometer	= 0.62137119 +	miles
1 meter	= 3.2808399 −	feet
1 meter	= 39.370079 −	inches

1 mile	= 1.609344	kilometers
1 foot	= 0.3048	meters
1 inch	= 25.4	millimeters

AREA and VOLUME

1959-FOOT SYSTEM

1 sq. mile	= 640 acres
1 acre (A)	= 10 sq. ch.
1 acre	= 43560 sq. ft.

METRIC SYSTEM

1 sq. kilometer	= 100 hectares (ha)
1 hectare	= 100 ares
1 are	= 100 sq. meters

CONVERSION 1959-FOOT SYSTEM AND METRIC SYSTEM

1 hectare	= 2.4710538 +	acres
1 cu. meter	= 1.30795 +	cu. yards
1 cu. cm.	= 0.0610237 +	cu. in.

1 acre	= 0.40468564 +	hectares
1 cu. yard	= 0.764555 −	cu. meters
1 cu. inch	= 16.3870 +	cu. cm.

Note. In 1959, the Foot System was redefined by agreement among officials of the nations where it is used, as follows: 1 yard = 0.9144 International Meter exactly. This reduced the lengths of units of the existing United States Foot System approximately 2 parts in 1,000,000. The then existing United States system was defined as follows: 39.37 inches = 1 International Meter and the foot in that system is now called the American Survey Foot. The American Survey Foot is still used by the U. S. Coast and Geodetic Survey and therefore applies to all the horizontal and vertical control nets in the United States. This exception is essential, as all data in feet published by that Bureau are the result of conversion from International Meters according to the definition 39.37 inches = 1 International Meter.

TABLE C

CONVERSION OF TIME TO ARC

HOURS OF TIME INTO ARC

T.	A.	T.	A.	T.	A.	T.	A.	T.	A.	T.	A.
hrs.	°	hrs.	°	hrs.	°	hrs.	°	hrs.	°	hrs.	°
1	15	5	75	9	135	13	195	17	255	21	315
2	30	6	90	10	150	14	210	18	270	22	330
3	45	7	105	11	165	15	225	19	285	23	345
4	60	8	120	12	180	16	240	20	300	24	360

MINUTES OF TIME TO ARC
SECONDS OF TIME TO ARC

Min. / *Sec.*	° / ′	′ / ″	Min. / *Sec.*	° / ′	′ / ″	Min. / *Sec.*	° / ′	′ / ″
1	0	15	21	5	15	41	10	15
2	0	30	22	5	30	42	10	30
3	0	45	23	5	45	43	10	45
4	1	0	24	6	0	44	11	0
5	1	15	25	6	15	45	11	15
6	1	30	26	6	30	46	11	30
7	1	45	27	6	45	47	11	45
8	2	0	28	7	0	48	12	0
9	2	15	29	7	15	49	12	15
10	2	30	30	7	30	50	12	30
11	2	45	31	7	45	51	12	45
12	3	0	32	8	0	52	13	0
13	3	15	33	8	15	53	13	15
14	3	30	34	8	30	54	13	30
15	3	45	35	8	45	55	13	45
16	4	0	36	9	0	56	14	0
17	4	15	37	9	15	57	14	15
18	4	30	38	9	30	58	14	30
19	4	45	39	9	45	59	14	45
20	5	0	40	10	0	60	15	0

HUNDREDTHS OF A SECOND OF TIME TO ARC

100ths of sec. of time s.	.00 ″	.01 ″	.02 ″	.03 ″	.04 ″	.05 ″	.06 ″	.07 ″	.08 ″	.09 ″
0.00	0.00	0.15	0.30	0.45	0.60	0.75	0.90	1.05	1.20	1.35
.10	1.50	1.65	1.80	1.95	2.10	2.25	2.40	2.55	2.70	2.85
.20	3.00	3.15	3.30	3.45	3.60	3.75	3.90	4.05	4.20	4.35
.30	4.50	4.65	4.80	4.95	5.10	5.25	5.40	5.55	5.70	5.85
.40	6.00	6.15	6.30	6.45	6.60	6.75	6.90	7.05	7.20	7.35
0.50	7.50	7.65	7.80	7.95	8.10	8.25	8.40	8.55	8.70	8.85
.60	9.00	9.15	9.30	9.45	9.60	9.75	9.90	10.05	10.20	10.35
.70	10.50	10.65	10.80	10.59	11.10	11.25	11.40	11.55	11.70	11.85
.80	12.00	12.15	12.30	12.45	12.60	12.75	12.90	13.05	13.20	13.35
.90	13.50	13.65	13.80	13.95	14.10	14.25	14.40	14.55	14.70	14.85

TABLE D

TEMPERATURE CORRECTIONS FOR STEEL TAPES
BASED ON COEF. OF EXP. OF 0.00000645 PER DEGREE

For these temperatures subtract correction	Correction per 1000 ft.	For these temperatures add correction	For these temperatures subtract correction	Correction per 1000 ft.	For these temperatures add correction
68°F.	.00000	68°F.	28°F.	.25800	108°F.
67	.00645	69	27	.26445	109
66	.01290	70	26	.27090	110
65	.01935	71	25	.27735	111
64	.02580	72	24	.28380	112
63	.03225	73	23	.29025	113
62	.03870	74	22	.29670	114
61	.04515	75	21	.30315	115
60	.05160	76	20	.30960	116
59	.05805	77	19	.31605	117
58	.06450	78	18	.32250	118
57	.07095	79	17	.32895	119
56	.07740	80	16	.33540	120
55	.08385	81	15	.34185	121
54	.09030	82	14	.34830	122
53	.09675	83	13	.35475	123
52	.10320	84	12	.36120	124
51	.10965	85	11	.36765	125
50	.11610	86	10	.37410	126
49	.12255	87	9	.38055	127
48	.12900	88	8	.38700	128
47	.13545	89	7	.39345	129
46	.14190	90	6	.39990	130
45	.14835	91	5	.40635	
44	.15480	92	4	.41280	
43	.16125	93	3	.41925	
42	.16770	94	2	.42570	
41	.17415	95	1	.43215	
40	.18060	96	0	.43860	
39	.18705	97	−1	.44505	
38	.19350	98	−2	.45150	
37	.19995	99	−3	.45795	
36	.20640	100	−4	.46440	
35	.21285	101	−5	.47085	
34	.21930	102	−6	.47730	
33	.22575	103	−7	.48375	
32	.23220	104	−8	.49020	
31	.23865	105	−9	.49665	
30	.24510	106	−10	.50310	
29	.25155	107	−11	.50955	

Example: Measured distance at 29°F. = 782.36
Correction −.25155 x .782 = −.20
Corrected Length = 782.16

CORRECTION FOR MERIDIAN CONVERGENCE

Apply when traverse angles are checked by celestial observation.

$$C = \Delta\lambda \sin \phi \qquad C'' = 52.13 \text{ m} \tan \phi$$

where: C is angular convergence, $\Delta\lambda$ is long. diff., ϕ is mean lat., m is distance east or west in miles.

CORRECTION FOR SLOPE

Square the difference in height of the two ends and divide by twice the slope measurement. Subtract the result from the slope measurement.

Slope meas. 100 ft. Diff. in ht. 12 ft.

$$100 - \frac{144}{200} = 99.28 \text{ ft. (error 0.003 ft.)}$$

CORRECTION FOR CURVATURE and REFRACTION IN LEVELING

The correction equals $-.000209\ S^2$ where S is the number of hundreds of feet in the sight.

Length of sight 220 ft. Rod reading	= 8.276
Correction: $-.000209\ (2.2)^2$	= $-.001$
Corrected reading	= 8.275

PROBABLE ERROR

If d_1, d_2, d_3, etc. are the discrepancies of various results from the mean, and if Σd^2 = the sum of the squares of these differences, and n = the number of observations, then the Probable Error is computed thus:

$$\text{P.E. Mean} = \pm\, 0.6745 \sqrt{\frac{\Sigma d^2}{n(n-1)}}$$

$$\text{P.E. One Obser.} = \pm\, 0.6745 \sqrt{\frac{\Sigma d^2}{n-1}}$$

MEASUREMENT EQUIVALENTS

π	= 3.1415927−	log = 0.49714987
1 radian	= 57.295780− deg.	log = 1.75812263
1 radian	= 3437.7468− min.	log = 3.53627388
1 radian	= 206264.81− sec.	log = 5.31442513
1 degree	= 0.017453293− rad.	log = 8.24187737 − 10
1 minute	= 0.000290888+ rad.	log = 6.46372612 − 10
1 second	= 0.000004848+ rad.	log = 4.68557487 − 10

TRIGONOMETRIC FORMULAS

$\frac{\sin A}{\cos A}=\tan A \qquad \sin^2 A+\cos^2 A=1 \qquad \tan^2 A+1=\sec^2 A$

$\sin A=\frac{1}{\csc A}=\cos(90°-A)=\frac{\tan A}{\pm\sqrt{\tan^2 A+1}}$

$\cos A=\frac{1}{\sec A}=\sin(90°-A)=\frac{1}{\pm\sqrt{\tan^2 A+1}}$

$\tan A=\frac{1}{\cot A}=\cot(90°-A)=\frac{\sin A}{\pm\sqrt{1-\sin^2 A}}=\frac{\pm\sqrt{1-\cos^2 A}}{\cos A}$

$\sin(A\pm B)=\sin A\cos B\pm\cos A\sin B$

$\cos(A\pm B)=\cos A\cos B\mp\sin A\sin B$

$\tan(A\pm B)=\frac{\tan A\pm\tan B}{1\mp\tan A\tan B} \qquad \cot(A\pm B)=\frac{\cot A\cot B\mp 1}{\cot B\pm\cot A}$

$\sin(A\pm 90°)=\pm\cos A \qquad \cos(A\pm 90°)=\mp\sin A$

$\sin(180°\pm A)=\mp\sin A \qquad \cos(180°\pm A)=-\cos A$

$\sin A+\sin B=2\sin\frac{1}{2}(A+B)\cos\frac{1}{2}(A-B)$

$\sin A-\sin B=2\cos\frac{1}{2}(A+B)\sin\frac{1}{2}(A-B)$

$\cos A+\cos B=2\cos\frac{1}{2}(A+B)\cos\frac{1}{2}(A-B)$

$\cos A-\cos B=-2\sin\frac{1}{2}(A+B)\sin\frac{1}{2}(A-B)$

$\sin 2A=2\sin A\cos A$

$\cos 2A=\cos^2 A-\sin^2 A=1-2\sin^2 A=2\cos^2 A-1$

$\tan 2A=\frac{2\tan A}{1-\tan^2 A} \qquad \cot 2A=\frac{\cot^2 A-1}{2\cot A}$

$\sin\frac{1}{2}A=\pm\sqrt{\frac{1}{2}(1-\cos A)} \qquad \cos\frac{1}{2}A=\pm\sqrt{\frac{1}{2}(1+\cos A)}$

$\tan\frac{1}{2}A=\frac{1-\cos A}{\sin A}=\frac{\sin A}{1+\cos A}=\frac{1}{\cot\frac{1}{2}A}$

SOLUTION OF OBLIQUE TRIANGLES

Angles are A, B, C. Sides opposite are a, b, c respectively.

Case I given a, B, C.

$$A = 180° - (B + C) \qquad b = \frac{a}{\sin A} \sin B$$

$$c = \frac{a}{\sin A} \sin C$$

Case II given a, b, A.

$$\sin B = \frac{\sin A}{a} b \qquad C = 180° - (A + B)$$

$$c = \frac{a}{\sin A} \sin C$$

Case III given a, b, C.

$$A + B = 180° - C$$

$$\tan \tfrac{1}{2}(A - B) = \frac{a - b}{a + b} \tan \tfrac{1}{2}(A + B)$$

$$A = \tfrac{1}{2}(A + B) + \tfrac{1}{2}(A - B)$$
$$B = \tfrac{1}{2}(A + B) - \tfrac{1}{2}(A - B)$$

$$c = \frac{a}{\sin A} \sin C$$

Case III given a, b, C: *alternate method.*

$$c^2 = a^2 + b^2 - 2ab \cos C$$

$$\cos A = \frac{b^2 + c^2 - a^2}{2bc} \quad \text{or} \quad \sin A = \frac{\sin C}{c} a$$

$$\cos B = \frac{a^2 + c^2 - b^2}{2ac} \quad \text{or} \quad \sin B = \frac{\sin C}{c} b$$

$$\text{or} \quad B = 180 - (A + C)$$

Case IV given a, b, c.

$$\text{let} \quad s = \tfrac{1}{2}(a + b + c)$$

$$\text{and } r = \sqrt{\frac{(s - a)(s - b)(s - c)}{s}}$$

$$\tan \tfrac{1}{2}A = \frac{r}{s - a} \qquad \tan \tfrac{1}{2}B = \frac{r}{s - b} \qquad \tan \tfrac{1}{2}C = \frac{r}{s - c}$$

Case IV given a, b, c: *alternate method.*

$$\cos A = \frac{b^2 + c^2 - a^2}{2bc} \qquad \cos B = \frac{a^2 + c^2 - b^2}{2ac}$$

$$\cos C = \frac{a^2 + b^2 - c^2}{2ab} \quad \text{or} \quad C = 180° - (A + B)$$

$$\text{Area} = \tfrac{1}{2}bc \sin A = \frac{a^2 \sin B \sin C}{2 \sin A}$$
$$= \sqrt{s(s - a)(s - b)(s - c)}$$

LOGARITHMS OF NUMBERS

N.	0	1	2	3	4	5	6	7	8	9	d
10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374	40
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755	37
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106	33
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430	31
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732	29
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014	27
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279	25
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529	24
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765	23
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989	21
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	21
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	20
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	19
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	18
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	17
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	17
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	16
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	16
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	15
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	14
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	14
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	13
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	13
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	13
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	13
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	12
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	12
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	12
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	12
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	11
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	11
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	10
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	10
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	10
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	10
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	10
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	9
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	9
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	9
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	9
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	9
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	8
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	8
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	8
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	8
N.	0	1	2	3	4	5	6	7	8	9	d

N.	0	1	2	3	4	5	6	7	8	9	d
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	8
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	8
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	7
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	8
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	8
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	7
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	7
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	6
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	7
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	7
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	6
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	7
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	6
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	6
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	6
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	7
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	6
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	6
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	6
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	6
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	6
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	6
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	6
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	5
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	6
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	6
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	5
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	5
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	5
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	5
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	5
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	5
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	5
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	5
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	4
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	4
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	5
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	5
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	4
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	4
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	5
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	5
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	4
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	4
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996	4
N.	0	1	2	3	4	5	6	7	8	9	d

NATURAL FUNCTIONS

°	sine	Diff. 1′	tang	Diff. 1′	cotang	Diff. 1′	cosine	Diff. 1′	°
0	.00000		.00000		Inf.		1.00000		90
		29.08		29.10				.25	
1	.01745		.01746		57.2900		.99985		89
		29.08		29.10				.77	
2	.03490		.03492		28.6363		.99939		88
		29.07		29.15				1.27	
3	.05234		.05241		19.0811		.99863		87
		29.03		29.20				1.78	
4	.06976		.06993		14.3007		.99756		86
		29.00		29.27				2.28	
5	.08716		.08749		11.4301		.99619		85
		28.95		29.35				2.78	
6	.10453		.10510		9.51436		.99452		84
		28.90		29.47				3.28	
7	.12187		.12278		8.14435		.99255		83
		28.33		29.60				3.80	
8	.13917		.14054		7.11537		.99027		82
		28.77		29.73				4.30	
9	.15643		.15838		6.31375		.98769		81
		28.70		29.92				4.80	
10	.17365		.17633		5.67128		.98481		80
		28.60		30.08		877.88		5.30	
11	.19081		.19438		5.14455		.98163		79
		28.50		30.30		733.20		5.80	
12	.20791		.21256		4.70463		.97815		78
		28.40		30.52		621.92		6.30	
13	.22495		.23087		4.33148		.97437		77
		28.28		30.77		534.50		6.78	
14	.24192		.24933		4.01078		.97030		76
		28.17		31.03		464.55		7.28	
15	.25882		.26795		3.73205		.96593		75
		28.03		31.33		407.73		7.78	
16	.27564		.28675		3.48741		.96126		74
		27.88		31.63		360.93		8.27	
17	.29237		.30573		3.27085		.95630		73
		27.75		31.98		321.95		8.73	
18	.30902		.32492		3.07768		.95106		72
		27.58		32.35		289.12		9.23	
19	.32557		.34433		2.90421		.94552		71
		27.42		32.73		261.22		9.72	
20	.34202		.36397		2.74748		.93969		70
		27.25		33.15		237.32		10.18	
21	.35837		.38386		2.60509		.93358		69
		27.07		33.62		216.67		10.67	
22	.37461		.40403		2.47509		.92718		68
		26.87		34.07		198.73		11.13	
23	.39073		.42447		2.35585		.92050		67
		26.68		34.60		183.02		11.58	
24	.40674		.44523		2.24604		.91355		66
		26.47		35.13		169.22		12.07	
25	.42262		.46631		2.14451		.90631		65
		26.25		35.70		157.02		12.53	
26	.43837		.48773		2.05030		.89879		64
		26.03		36.33		146.15		12.97	
27	.45399		.50953		1.96261		.89101		63
		25.80		36.97		136.47		13.43	
28	.46947		.53171		1.88073		.88295		62
		25.57		37.67		127.80		13.88	
29	.48481		.55431		1.80405		.87462		61
		25.32		38.40		120.00		14.32	
30	.50000		.57735		1.73205		.86603		60
		25.07		39.18		112.95		14.77	
31	.51504		.60086		1.66428		.85717		59
		24.80		40.02		106.58		15.20	
32	.52992		.62487		1.60033		.84805		58
		24.53		40.90		100.78		15.63	
33	.54464		.64941		1.53986		.83867		57
		24.25		41.83		95.50		16.05	
34	.55919		.67451		1.48256		.82904		56
		23.98		42.83		90.68		16.48	
35	.57358		.70021		1.42815		.81915		55
		23.68		43.88		86.28		16.88	
36	.58779		.72654		1.37638		.80902		54
		23.38		45.02		82.23		17.30	
37	.60182		.75355		1.32704		.79864		53
		23.07		46.23		78.50		17.72	
38	.61566		.78129		1.27994		.78801		52
		22.77		47.48		75.07		18.10	
39	.62932		.80978		1.23490		.77715		51
		22.45		48.87		71.92		18.52	
40	.64279		.83910		1.19175		.76604		50
		22.72		50.32		68.97		18.88	
41	.65606		.86929		1.15037		.75471		49
		21.78		51.85		66.27		19.28	
42	.66913		.90040		1.11061		.74314		48
		21.45		53.53		63.73		19.65	
43	.68200		.93252		1.07237		.73135		47
		21.10		55.28		61.40		20.02	
44	.69466		.96569		1.03553		.71934		46
		20.75		57.18		59.22		20.38	
45	.70711		1.00000		1.00000		.70711		45
°	cosine		cotang		tang		sine		°

CELESTIAL OBSERVATIONS

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I. THE PRINCIPLES UPON WHICH CELESTIAL OBSERVATIONS ARE BASED

A. CONCEPTS

1. The Celestial Sphere. To simplify the computations necessary for the determinations of the direction of the meridian, of latitude, and of longitude or time, certain concepts of the heavens have been generally adopted. They are the following:

a. The earth is stationary.

b. The heavenly bodies have been projected outward, along lines which extend from the center of the earth, to a sphere of infinite radius called the ***celestial sphere.***

The celestial sphere has the following characteristics:

a. Its center is at the center of the earth.

b. Its equator is on the projection of the earth's equator.

c. With respect to the earth, the celestial sphere rotates from east to west about a line which coincides with the earth's axis. Accordingly, the poles of the celestial sphere are at the prolongations of the earth's poles.

d. The speed of rotation of the celestial sphere is 360° 59.14′ per 24 hours.

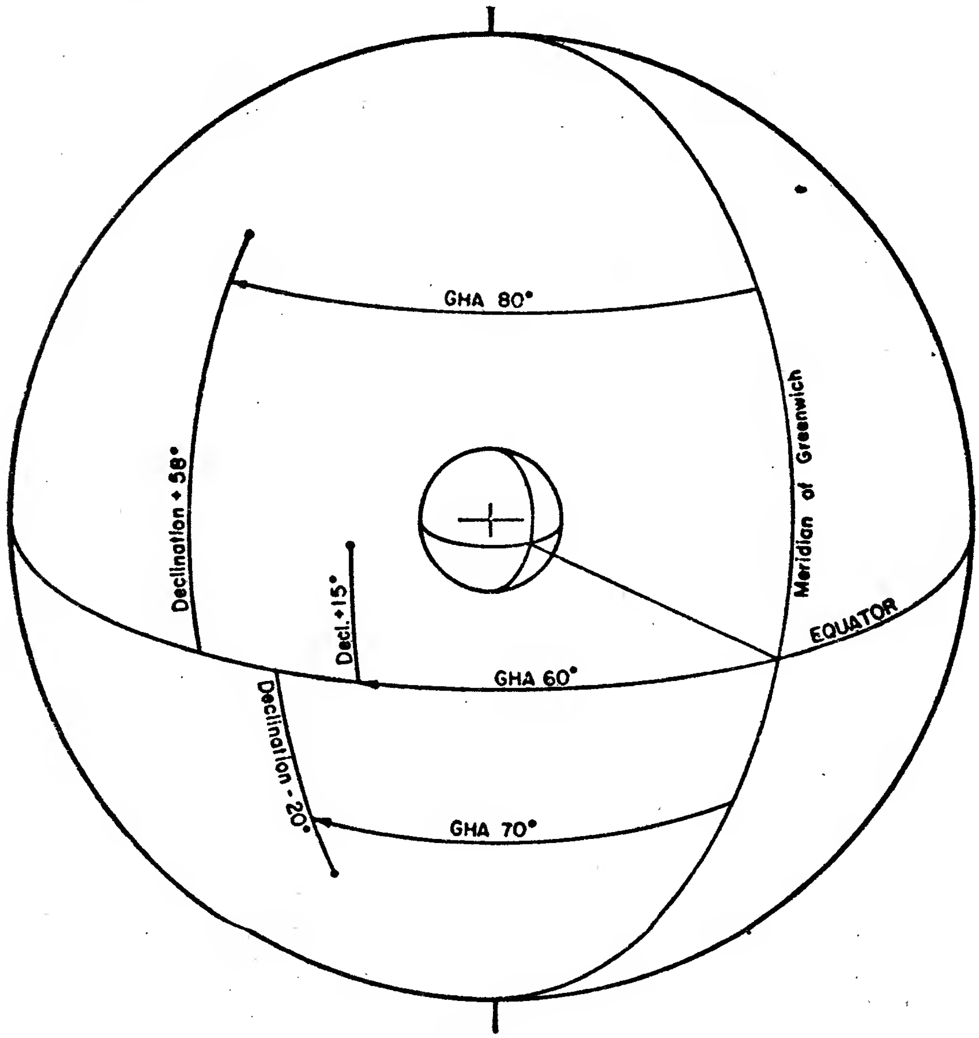


Fig. 1.

e. With the important exception of bodies in the solar system, which change position slowly, all heavenly bodies remain practically fixed in their positions on the celestial sphere, never changing more than negligible amounts in 24 hours, and accordingly are often called *fixed stars*.

2. The Position of a Heavenly Body. (Fig. 1) The position of any heavenly body with respect to the earth, at any moment, is given by its ***declination*** (d) and its ***Greenwich Hour Angle*** (*GHA*)*.

* The position of a heavenly body in the celestial sphere is given by its declination and right ascension. The concept of right ascension is unnecessary in this discussion and is omitted for simplicity.

3. Declination. A plus declination is the angular distance measured north from the equator. An angular distance measured south from the equator is a minus declination. A declination therefore is equivalent to a latitude.

Table 1 can be used to obtain the sun's declination at any moment of time throughout the year, Table 3 gives the declination of Polaris at ten-day intervals, and Table 13 gives the declinations of twenty-six selected stars.

4. Greenwich Hour Angle. The *GHA* is the angle measured from the meridian of Greenwich westward to the meridian over which the body stands at any moment. Up to 180°, a *GHA* is equivalent to west longitude, and thereafter it continues up to 360°. Thus the *GHA's* of all heavenly bodies are always *increasing* as the heavens move toward the west. Table 1 lists the *GHA* of Polaris at the moment of Greenwich midnight (0^h) for each day of the year. Since the angular speed of rotation of the celestial sphere is known, the increase in the *GHA* that occurs after Greenwich midnight can be computed for any time of day. Table 5 is a multiplication table which facilitates this computation.

5. Time. The word *time* has two meanings that are often confused, ***elapsed time*** and ***moment of time.***

The measure of elapsed time used throughout this treatise is the familiar hour of which there are 24 in a day. Elapsed time, so measured, is more accurately called Mean Solar Time (*MST*), Mean Time (*MT*), or Civil Time (*CT*).

A moment of time is given by the year, the day of the month and the elapsed time since midnight (0^h) at the beginning of the day named. It must be further defined by the meridian from which it is reckoned. Accordingly, ***Greenwich Civil Time*** (*GCT*), often

called ***Universal Time,*** is civil time reckoned from the moment of midnight at the Greenwich meridian; and 75th meridian time (Eastern Standard Time, *EST*), for example, is civil time reckoned from midnight at the 75th meridian. ***Local Civil Time*** (*LCT*) is civil time reckoned from the precise meridian of longitude where an observation is taken. To convert a moment of time, reckoned from any meridian, to *GCT*, one hour is added for every 15° of west longitude and one hour is subtracted for every 15° of east longitude. Obviously, when the value of the longitude is not evenly divisible by 15°, fractional hours will result.

Examples:

1 AM *EST*	=	6^h *GCT*
2 PM *EST*	=	19^h *GCT*
10 PM *EST*	=	3^h *GCT* (the next day)
4 AM 76°W *LCT*	=	$9^h\ 4^m$ *GCT*
10 AM 30°E *LCT*	=	8^h *GCT*

6. Tables and Charts. This book contains all the tables necessary for observations on the sun, on Polaris and on twenty-six selected stars. For other stars the reader is referred to "The American Nautical Almanac" published for each year by the U. S. Naval Observatory and available from the Superintendent of Documents, Washington, D. C.

Note that the word *apparent* is often found preceding data in tables. It means that the data given are those which would result if the observation were made at the center of the earth. Since all computations are based on this premise and all observations are corrected accordingly, these are the data to use. When the word *apparent* is omitted it is understood to be there.

Two star charts are provided; Fig. 6, which shows the northern sky, and Fig. 10, which shows the sky when looking south.

7. The Sun. As the earth traverses its yearly path, the background of the celestial sphere

behind the sun changes slightly from day to day. Viewed from the earth, the sun apparently completes a circuit around the celestial sphere once in the course of a year. Accordingly the rate of increase in the *GHA* of the sun differs slightly from the rate of increase of the *GHA* of the fixed stars, which move very nearly with the celestial sphere.

Since the earth's axis slants with respect to the plane of the earth's path around the sun, the sun moves north and south on the celestial sphere as the earth moves along its path. This causes the sun's declination to change more rapidly than do the nearly constant declinations of fixed stars. In the course of a year the sun's declination ranges almost 23½° each way north and south of the equator. For these reasons, special tables are necessary for the sun.

The sun does not make its daily passage around the earth at a constant rate. For this reason it is impossible to base elapsed time on the daily passage of the sun. The 24 hour unit used for the day is based on the *average* rate of movement of the sun. In fact the sun is sometimes ahead of and sometimes behind noon *LCT* by an amount which varies from zero to about 16 minutes. (See next section.)

8. The Equation of Time is the *GHA* of the sun minus the *GHA* of noon *LCT*. But for all practical purposes it may be defined as the elapsed time by which the sun precedes noon *LCT*. A minus value indicates that the sun follows noon *LCT*. For example, the following data can be true.

Moment of Time	Position of Sun	Equation of Time
12^h *GCT*	*GHA* 3° 8.4′	$+12^m\ 33.6^s$
12^h *GCT*	*GHA* 356° 37.1′	$-13^m\ 31.6^s$

Table 1 can be used to find the value of the equation of time for any moment of time throughout the year.

9. True Solar Time is, for all practical purposes, a moment of time measured in civil hours

but based on the sun's passage for the day in question. Noon (12^h) true solar time on any day and at any meridian is the moment the sun crosses that meridian that day. Accordingly, at any given meridian:

$$\text{or}\left\{\begin{array}{ll}\text{True Solar Time} = & \text{Local Civil Time} \\ & + \text{Equation of Time} \\ \text{Local Civil Time} = & \text{True Solar Time} \\ & - \text{Equation of Time}\end{array}\right\} \quad (1)$$

B. THE TRIGONOMETRY INVOLVED

10. A Spherical Triangle. A ***great circle*** is the trace on a sphere of a plane which passes through the center of the sphere. A ***spherical triangle*** is the figure on a sphere bounded by the arcs of three great circles. It has six parts: three sides and three angles. When any three parts are known, the other three can be found. Both sides and angles are measured in angular units, usually in degrees and minutes. The length of a side is measured by the angle at the center of the sphere between the radii extended to its ends. The size of an angle is measured by the dihedral angle between the planes of the great circles which form it. It may also be measured by the angle between the tangents to the great circles at their intersection.

Any three points on a sphere may be joined by great circles to form a triangle in which no part is greater than 180°. Such a triangle is the one always considered in this text.

11. The Principles. Fig. 2 illustrates the spherical trigonometry involved in every observation for position or for true north. It represents the conditions that exist at the moment of observation. *P* is a pole of the celestial sphere (in this case the north pole),*

*The south pole may be used, but the signs of the latitude and the declination must then be reversed. To avoid confusion, the symbol *P* in this text is always taken as the north pole.

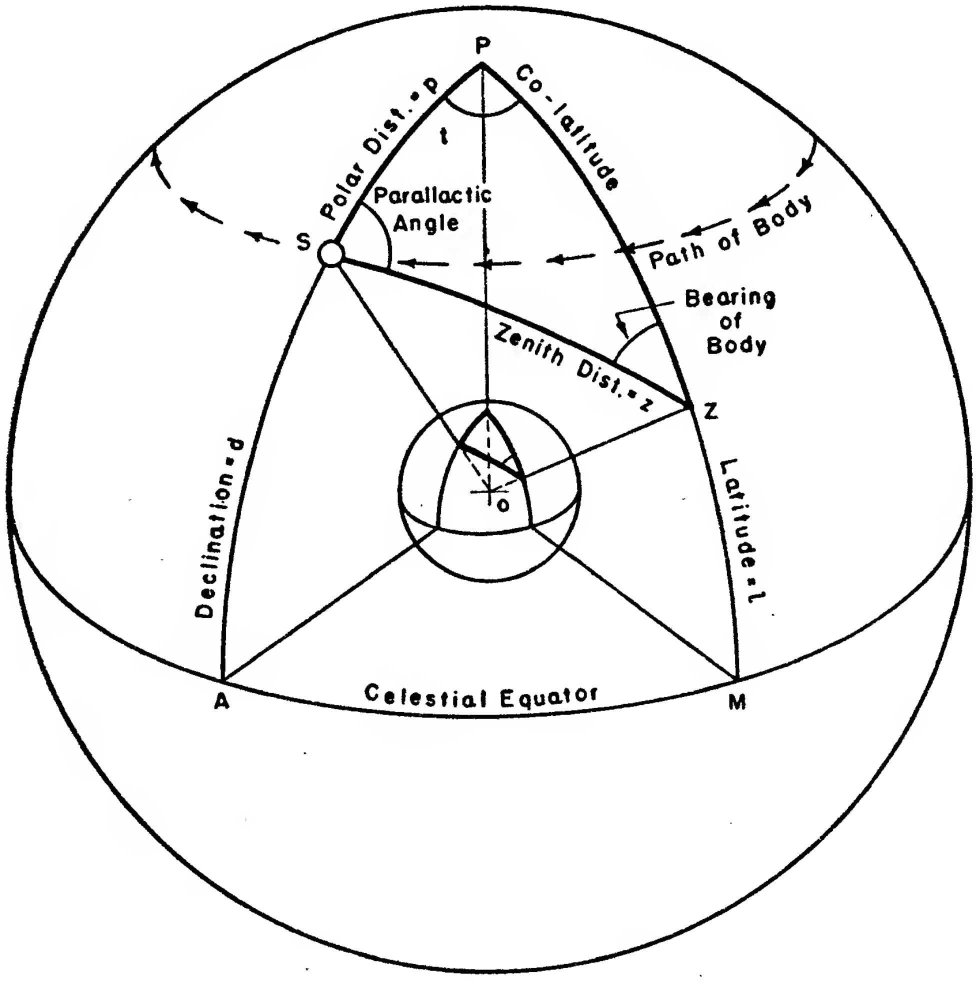


Fig. 2.

S is the celestial body observed (the arrows represent the path of the body) and *Z* is the observer's zenith. The lines joining them are arcs of great circles.

12. The Zenith. The observer's zenith is a point on the celestial sphere found by projecting the center of the instrument at the time of observation upward along the direction opposite to that of gravity.

13. The Astronomical Triangle. (Fig. 2.) The triangle *PZS* is known as the ***astronomical triangle.*** It may be formed west of the meridian as shown, or east of the meridian if the body is so located. It is a true spherical triangle formed by great circles, and spherical

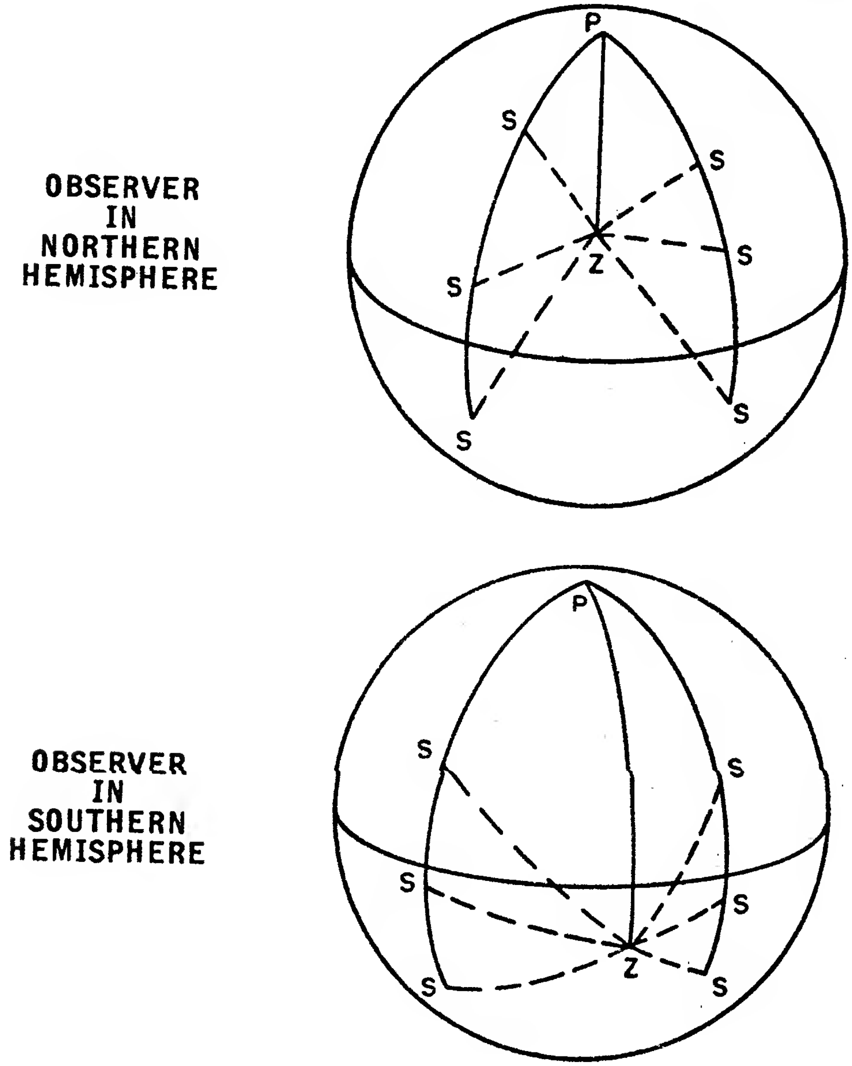


Fig. 3.

trigonometric formulas apply. When Z or S, or both, are in the southern hemisphere, other arrangements are created. Fig. 3 shows the twelve possibilities. Note that no angle or side is greater than 180°. All forms of the triangle are solved by the same formulas but the results of the solutions do not indicate whether the body is east or west of the meridian. This can be determined from the *LHA* described in the next paragraph. The six parts of the triangle are named and described below.

14. Angle t is known as the ***meridian angle***. The ***Local Hour Angle*** (*LHA*) of a body is the angle measured westward around the axis of the celestial sphere from the meridian of

the observation to the meridian of the body. The arc MA represents the LHA. Obviously

$$LHA = GHA - \text{West Longitude} \ldots\ldots (2)$$
$$LHA = GHA + \text{East Longitude} \ldots\ldots (2a)$$

When the LHA is less than 180°, the body is west of north and:

$t = LHA$

When the LHA is greater than 180°, the body is east of north and:

$t = 360° - LHA$

15. Angle *Z* is the bearing* of the body S, since it is equal to the horizontal angle between the north direction of the observer's meridian and the direction of the body. It is measured east or west of north according to the position of the PZS triangle.

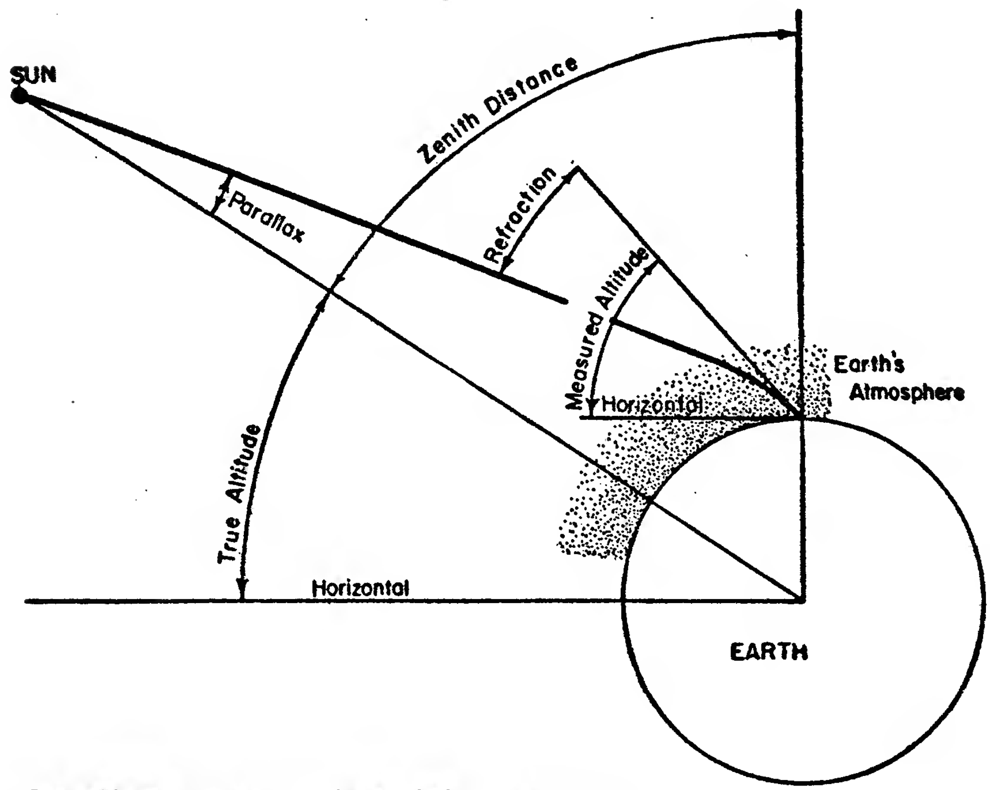
16. Angle *S* is the parallactic angle. It is usually unnecessary to use the value of this angle.

17. Side *PS* (p) is the *polar distance*. It is equal to 90° minus the declination (d) of the body S. In the formulas used for many observations sin d is substituted for cos p, etc.

18. Side *PZ* is the *co-latitude* of Z. It is equal to 90° minus the latitude (l) of the observer. The formulas are often written using sin l substituted for cos co-latitude, etc.

19. Side *ZS* (z) is the *zenith distance* of the body S. It is equal to 90° minus true altitude (h). The true altitude can be found in the field by observing the altitude of a body and correcting the result for *refraction* and *parallax*, as described in the next section.

*The term *bearing* is used here in preference to *azimuth* since the angle measured from the north may be either east or west. It may exceed 90° but it is always less than 180°.



True Altitude = Measured Altitude − Refraction + Parallax

Fig. 4.

20. Refraction and Parallax. Fig. 4 shows the effect of refraction and of parallax. The true altitude is obtained by the following formula:

$$\text{True Altitude} = h = \text{Measured Altitude} - \text{Refraction} + \text{Parallax} \quad (3)$$

The value of the refraction is affected by the altitude and to a lesser degree by the air density. Its effect can be estimated for the measured altitude and the ground temperature and barometric pressure or elevation. The sun's parallax is very small (never more than 0.2′) and the parallax of the stars is infinitesimal. Table 2 gives the values of refraction and the sun's parallax at a certain temperature and barometric pressure. Table 2a gives factors for correcting those values for actual temperature and barometric pressures (or elevations).

C. FIELD METHODS

21. Operations. The field operations consist of measuring vertical and horizontal angles to celestial bodies and recording the precise time that a body is sighted. Horizontal angles must, of course, be measured from an *azimuth mark* on the ground.

Usually several observations are made in a group, the angles and times averaged, and only the averages used in computation. At least two groups should be averaged and computed separately for a check. As a rule no single group should include observations made more than ten minutes apart, because of the curvature of the path of the body. The methods of observing are identical to ordinary surveying methods with the following additional requirements.

a. Pointing on a star. At dusk a star can be observed without special equipment. When the sky is so dark that the cross hairs cannot be seen, a flashlight should be pointed diagonally into the objective lens. The position of the flashlight can be regulated so that the stray light gives sufficient background to show the cross lines but is not so bright that the star is obliterated. K & E No. 74 0560 Reflector Sunshade provides the proper illumination when a flashlight is played on it from the side.

b. Illumination of azimuth mark. While any light will serve as a mark at night, it is best to provide an illuminated background for a plumb bob or other signal placed over the station. The cross lines can then be seen against the background without illuminating the instrument.

c. Pointing on the sun. The sun should not be observed through a telescope without protec-

tion for the eye. Methods for pointing on the sun are described in Section 30.

d. Set up. If the ground is springy, the tripod should be supported on firm stakes. Leveling must be extremely accurate to avoid serious errors. If the instrument is equipped with a telescope level, after leveling with the plate bubbles, proceed as follows.

Step 1. Set the vernier at zero, turn the instrument in azimuth until the telescope is in line with a pair of opposite leveling screws and center the telescope bubble with the vertical motion.

Step 2. Turn 180° in azimuth. If the bubble fails to center, correct half the error with the leveling screws, and the other half with the tangent screw.

Step 3. Repeat Steps 1 and 2 until the bubble remains in the center.

Step 4. Turn 90° in azimuth. Center the bubble with the leveling screws.

Step 5. Test the leveling at 0°, 90°, 180°, and 270°.

If the telescope is without a level, perfect the leveling until the plate level that is parallel to the telescope remains in the same position in the tube at all azimuths.

e. Recording time. For certain observations, time must be recorded within two or three seconds. For these observations the watch correction should be determined to the nearest second before, and preferably also after, the field work. Before comparison, the minute hand should be set so that it coincides exactly with a minute mark when the second hand is at zero. Accurate time is best obtained from radio time signals.

During the observation the transitman calls "tit" when his pointing is perfected. The recorder reads first the second, then the minute and the hour. When no recorder is available, a

stop watch is of great assistance. The observer starts the stop watch when the pointing on the body is correct and stops it when the second hand of the timing watch is on a 10 seconds mark. The reading of the stop watch is subtracted from that of the timing watch.

Example: If the stop watch is stopped at 6 seconds when the timing watch read 8:42:30, the stop watch was evidently started at 8:42:24. Therefore, the time of observation was 8:42:24.

II. DETERMINATION OF TRUE BEARING

METHOD 1. BY OBSERVATION OF POLARIS AT ELONGATION

22. Description. True north can be determined by a Polaris observation at elongation when accurate time is not available. The method is simple and, with care, should give results within ± 0.5 minutes. However, it often must be performed at inconvenient hours.

Polaris follows a circular path around the pole similar to that shown by the arrows in Fig. 2. Viewed from the earth, the path is circular and the motion is counterclockwise. The points in the path where Polaris is furthest west or furthest east are called *western* and *eastern elongation* respectively. When the parallactic angle S is 90° the star is at elongation.

23. Directions for Observation. Required to determine the bearing of a mark B from transit station A. (See Sec. 21). The instrument must be in perfect adjustment unless the star can be observed with the telescope both direct and reversed as mentioned below.

From observation of the sky or by means of Fig. 5 or Table 8, estimate the time of that elongation which occurs during dark. Set up at A. Set the horizontal vernier at zero. Sight B with the lower motion. Point on Polaris with the upper motion.

Before $\begin{Bmatrix}\text{western}\\\text{eastern}\end{Bmatrix}$ elongations the star will be moving $\begin{Bmatrix}\text{down}\\\text{up}\end{Bmatrix}$ and also moving toward the $\begin{Bmatrix}\text{west}\\\text{east}\end{Bmatrix}$.

Follow the star until the $\begin{Bmatrix}\text{westward}\\\text{eastward}\end{Bmatrix}$ movement ceases and the only movement is vertical. Read the horizontal vernier. The motion east or west is imperceptible for about 10 minutes. It therefore may be possible to repeat the angle with the telescope reversed — thus increasing the accuracy and eliminating errors of instrument adjustment.

24. Example. Date, Oct. 17, 1963; latitude (from map), 40° 20′; clockwise angle from mark B to Polaris, 75° 20′. Use the following formula or Table 7.

$$\text{Bearing of Polaris (in minutes)} = \frac{\text{Polar Distance (in minutes)}}{\cos \text{Latitude}} \quad \ldots\ldots (4)$$

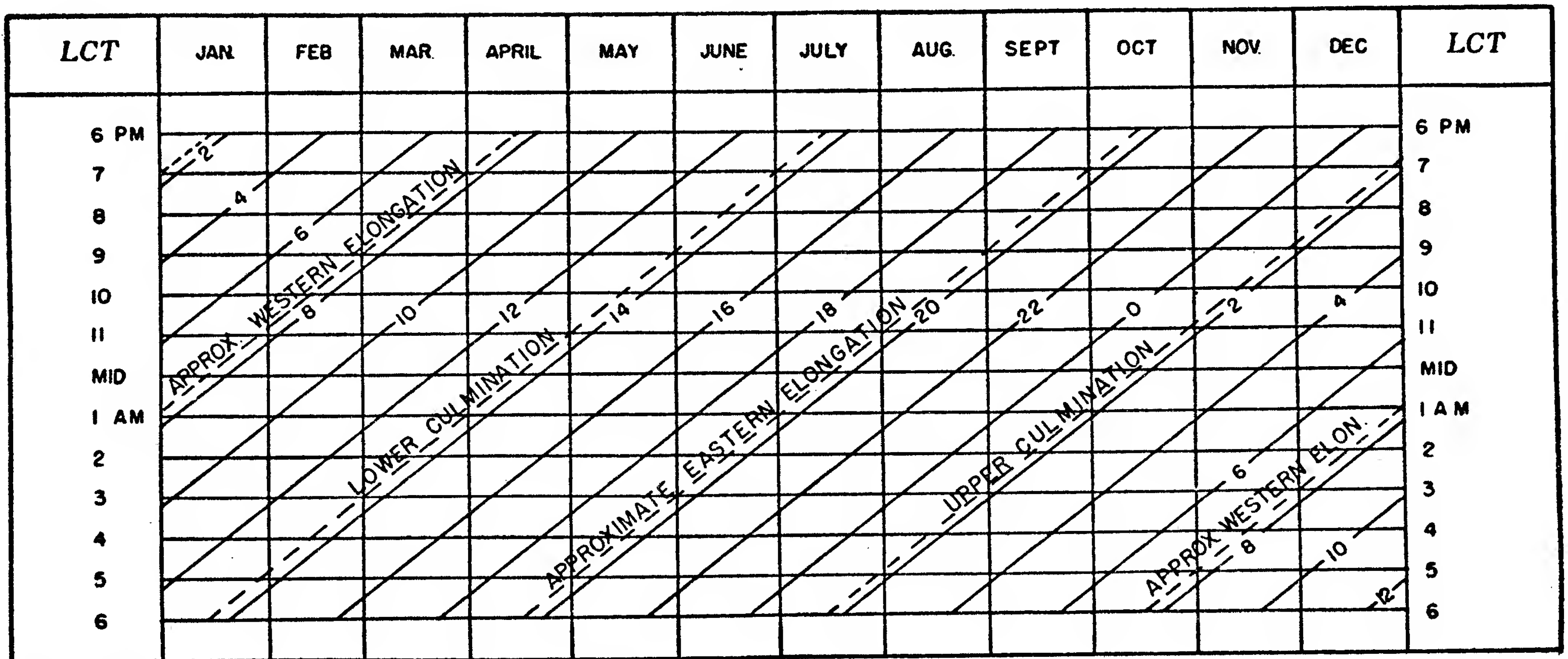
From Table 3 polar distance Polaris Oct. 17, 1963 = 0° 54.37′

$$Z = \frac{54.37'}{.7623} = 71.3' = 1^\circ 11.3'$$

From Table 7 azim. = 1° 11.3′

Bearing AB = N76° 31.3′W (if elong. was western)
= N74° 08.7′W (if elong. was eastern)

Fig. 5.



The *LCT* (see Sec. 5) used in the chart is substantially correct for any year. To convert watch time to *LCT*, add to the watch time 4 minutes for every degree of longitude that the observation is east of the meridian from which the watch time is reckoned. Subtract if west. Example: watch 10:00 *CST* (90th mer.); observation 87° W. Long. $10{:}00 + 3 \times 4 = 10{:}12$ (*LCT*). This conversion is necessary only when watch time and *LCT* differ substantially.

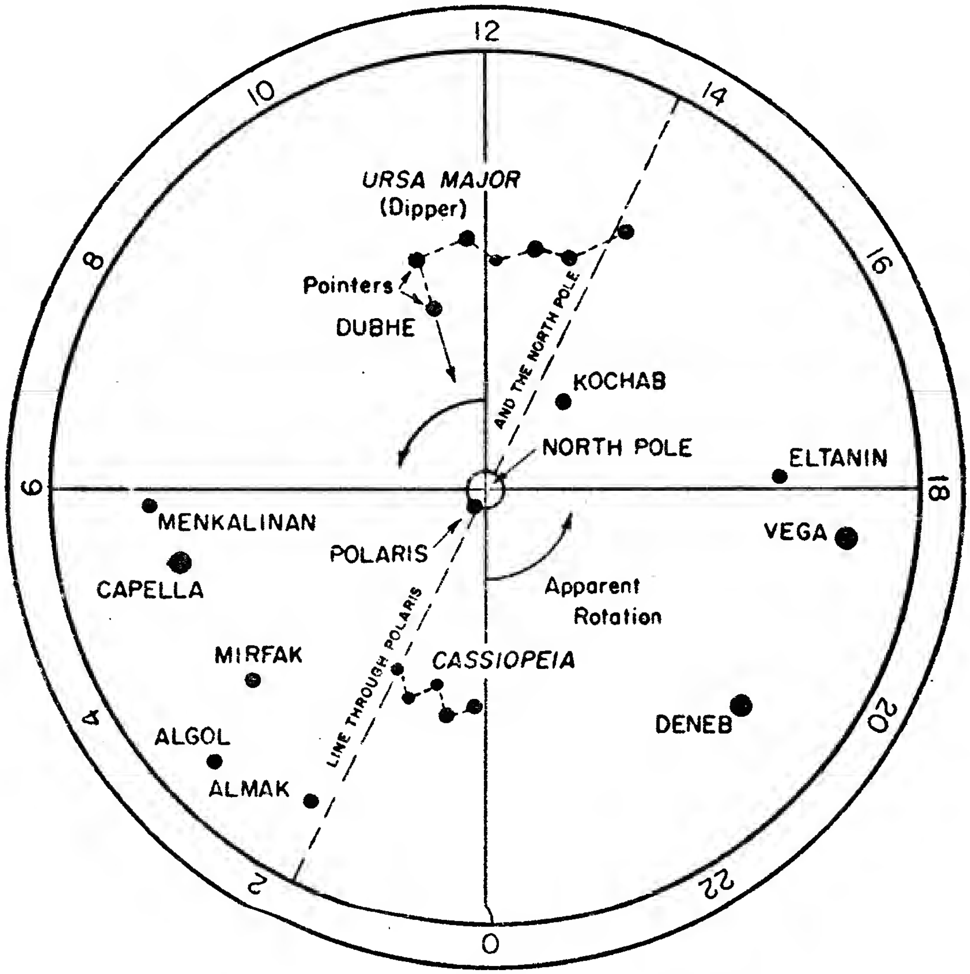


Fig. 6.

Figures 5 and 6 can be used to find the appearance of the northern sky at any time. On Fig. 5 read down from the date (month and approximate day) and across from the hour of the night. At the intersection read the number of the nearest slant line. This is the "hour line" that will be nearly above the observer as shown on any star chart. Fig. 6 is a chart of the northern sky. Revolve it so that this number on its rim is at the top.

Fig. 5 can also be used to find approximate times of elongations and culminations of Polaris by referring to the dotted slant lines. For example, on June 15 lower culmination occurs about 8 PM.

METHOD 2. BY OBSERVATION OF POLARIS AT ANY TIME

25. Description. The method described below is designed for accurate observation. It is quick and convenient, and the computations are simple. It can be made at any time from dusk to dawn. Twilight is recommended. Pointings can be made on the star at that time while the instrument can be set up and the angles read by daylight. Polaris can be easily seen through the telescope an hour before sunset. To find the star, estimate its place in the sky with respect to the pole to $\pm \frac{1}{4}°$ by means of Fig. 5. The telescope can be pointed to the pole by setting the vertical circle at the latitude and the compass needle at the magnetic bearing of the pole. By correcting these settings, according to its estimated position, the star can be brought into the field of view. A signal should be placed on the ground under the star about 30 feet from the instrument, to aid in finding the star again.

26. Directions for Observation. Required to determine the bearing of mark B from transit station A. Determine the watch correction to the nearest second. (See Sec. 21). Set up at A. Turn the angle from B to the star, using six repetitions of the angle, three with the telescope in its normal position and three in its reversed position, i.e. 3DR. Record the time to the nearest second each time the cross line is brought on the star. Average the time and divide the total angle by six. At least two separate observations should be made.

27. Example. Time of observation May 5, 1963; watch reading, 8:28:23 PM, 90th Meridian time; watch known to be 0:02:03 slow; latitude (from map) N42°22.6′; longitude (from map) W92° 58.3′; clockwise angle, mark to star **25° 53.0′.**

Find the *LHA* and *t* (see Sec. 14) as shown below.

Watch time		8:28:23 PM
Watch correction (slow is plus)		2:03 slow
Standard time (90th meridian)		8:30:26 PM
Correction to 24 hour basis	+	12
90th meridian time		20:30:26
Correction for time zone	+	6
GCT (Sec. 5)		26:30:26
GCT May 6, 1963		2:30:26
GHA (Sec. 2) 0^h May 6, 1963 Table 1		193° 55.7′
Correction for $2^h\ 30^m$ (Table 5)	+	37 36.2
Correction for 26^s (Table 5)	+	6.5
GHA		231° 38.4′
Less west longitude (from map)	−	92 58.3
LHA (Sec. 14)		138° 40.1′
t = *LHA* or 360 − *LHA* (use smaller)		138° 40.1′

28. Computation. The bearing of Polaris (*Z*) (Sec. 15) is found from the formula:

$$Z = \frac{\sin t}{\cos h} p \qquad (5)$$

where

t (Sec. 14) is the meridian angle just computed above.

h (Sec. 20) is the true altitude. It is usually obtained from the known latitude *l*, using Table 6, and then it need not be observed.

p (Sec. 17) is the polar distance.

Four optional procedures for the computation are given below. Procedure A is the solution which is familiar to K&E Solar Ephemeris users. Procedures B, C and D are added to give a more precise solution under different conditions of latitude and instrumentation.

Procedure A

Table 10 gives values of Z for selected values of LHA and l when $p = 0° 54.33'$. By a two-way interpolation the value of Z can be found from the known values of LHA and l. Table 11 gives the correction to be applied for values of p other than $0° 54.33'$.

Example.

LHA =	$l = 42°$	$42° 23'$	$44°$
135°	51.2′	51.5′	52.8′
138° 40′		48.1′	
140°	46.5′	46.8′	48.0′

From Table 3, p for May 6 = 54.58′; from Table 11, the correction for $p = 54.58'$ and $Z = 48.1'$ is $+ 0.2'$. Therefore

$$Z = 48.1' + 0.2' = 48.3'$$

Procedure B

For a precise computation, if the station is between N. Lat. 25° and N. Lat. 50° (latitudes of U. S. A.), use the formula

$$Z = \frac{\sin t}{\cos h} p \qquad \text{where}$$

Z (Sec. 15) is the bearing of Polaris expressed in minutes of arc with a computational accuracy of $\pm 0.02'$.

t (Sec. 14) is the meridian angle to the nearest minute.

h (Sec. 20) is the true altitude to the nearest minute from Table 6.

p (Sec. 17) is the polar distance expressed in minutes to the nearest 0.02′.

Example,

p (Sec. 17) for Polaris (Table 3, May 6, 1963)	54.58′
l (from map)	42° 22.6′
Correction (Table 6, t = 138.7°)	— 41.0′
h (Sec. 20)	41° 41.6′

$$Z = \frac{\sin 138° 40'}{\cos 41° 42'} \times 54.58' = \frac{.6604}{.7466} \times 54.58'$$

$$= 48.28'$$

Procedure C

For latitudes below 25° or above 50° where Polaris can be observed, greater accuracy can be achieved by measuring h directly, rather than by using a correction of l, provided the instrument has a full vertical circle. Use the same formula (Eq. 5) as above, but observe the altitude and the temperature and obtain the true altitude h by correcting for refraction. The altitude should be observed once direct at the first pointing on Polaris and once reversed at the last pointing on Polaris. The average is used. Assume the average measured altitude is 21° 10.0′, the temperature is 70°, and the barometer is 30.5 in.

$$
\begin{array}{rr}
\text{Measured altitude} = & 21^\circ\ 10.0' \\
\text{Less refraction correction} & \\
-2.46 \times 0.96 \times 1.03 \quad \text{(Table 2)} = - & 2.4 \\
\hline
h = & 21^\circ\ 07.6'
\end{array}
$$

Procedure D

When procedure C cannot be followed because the instrument has no vertical circle, use the following formula. (For cot p see Table 3).

$$Z \text{ in minutes} = \frac{(3438) \sin t}{\cos l \cot p - \sin l \cos t} \quad (6)$$

Example.

Z (minutes)

$$= \frac{(3438) \sin 138^\circ 40'}{\cos 42^\circ 23' \cot p - \sin 42^\circ 23' \cos 138^\circ 40'}$$

$$= \frac{(3438)\ (.6604)}{(.7387)\ (62.98)\ -\ (.67)\ (-.75)}$$

$Z = 48.28'$

To compute the bearing of the Mark. (Fig. 7). Having computed Z by any one of the above four procedures, continue as follows:

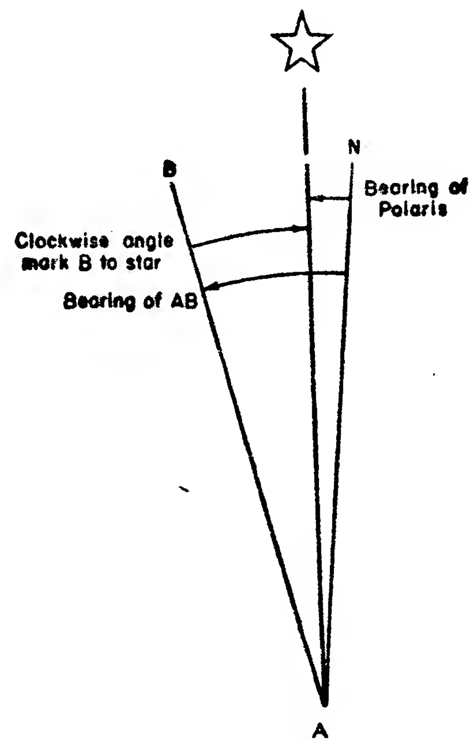


Fig. 7.

Since LHA is less than 180°, the star is west of north. Using the value 0°48.2′, the bearing of mark B is computed as follows. (See Sec. 14).

Clockwise angle mark B to star	25° 53.0′
Bearing of Polaris	+N 0° 48.3′ W
Bearing of AB	N 26° 41.3′ W

Note: When neither accurate time nor longitude are available, the GHA and the t of Polaris can be obtained by the method outlined on page 157.

METHOD 3. BY THE ALTITUDE OF THE SUN

29. Description. The bearing of a line can be determined to within ±2′ by an observation on the sun. The average of several such observations will, of course, give a higher accuracy.

30. Directions for Observation. Required to find the bearing of mark B from transit station A (Sec. 21). The observation should be made when the sun's altitude is at least 20° and at least two hours before or after noon. Correct time within ±10 minutes must be observed. The watch should be checked accordingly.

Set up at A using the telescope level as described in Sec. 21, Para. d. Set the *A* vernier at zero and, with the telescope direct, sight B, using the lower motion.

For direct observation of the sun a dark filter must be used such as K&E No. 74 0575 Prism and Colored Glass. A method preferred by many, however, is based on using the image of the sun that is formed on any white surface held behind the eyepiece. The latter method is described below, but the instructions can also be followed for direct observations through the telescope, the difference in the procedure being obvious.

To Sight the Sun. Have the recorder hold the back (white) page of the field book about six inches behind the eyepiece. With the upper and vertical clamps free, turn the telescope until its shadow on the page is circular. As the telescope is moved into this position, the sun's image will flash across the page. Bring the image within the shadow of the telescope and clamp both motions. Approximately center the sun in the shadow with the tangent screws. Adjust the distance between the field book page and the eyepiece until the cross lines can be seen most effectively. Focus the eyepiece until the images of the cross lines which appear on the sun's disc are clear cut, and focus the objective until the edge of the sun's image is sharp.

Identify the center horizontal cross line. It will be noticed that, as the sun's image is moved

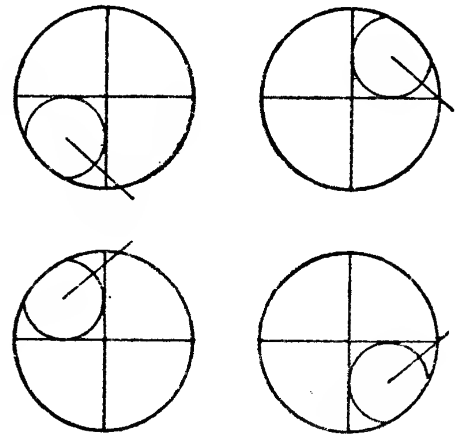


Fig. 8.

with the tangent screws, the cross lines remain stationary with respect to the shadow of the telescope. The center horizontal cross line will remain in the center of the shadow, while the stadia lines will be found at the top and bottom respectively.

To make the observations, the sun's image may be centered on the cross lines or brought tangent to them. The first method is simpler to perform, the second method is more accurate. If the second method is used, half of the observations should be made with the sun in one quadrant and the other half with the sun in the opposite quadrant. The mean of the results will then be the same as that which would have been obtained had the cross lines been centered. (See Fig. 8.)

While either pair of opposite quadrants may be used, the scheme illustrated in Fig. 8 is recommended. When using an erecting instrument, the sun's image moves in the same direction as a shadow that is cast by the sun. Fig. 8 shows this motion. If it is turned upside down Fig. 8 will illustrate an observation with an inverting instrument. In the southern hemisphere the horizontal components of the sun's motion will be in the opposite direction from those shown in Fig. 8. To make the

observation, a quadrant is chosen in which the sun's image is moving toward one cross line and away from the other. The disc is kept tangent to the line towards which it is moving but allowed to make its own tangency with the other line. When the moment of tangency occurs, stop moving the telescope and read the circles.

K&E makes a special reticule for solar observations illustrated in Fig. 9. It contains a circle which is very slightly smaller than the

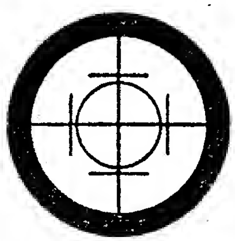


Fig. 9.

GLASS RETICULE for direct solar observation, with cross and short stadia lines and solar circle. The semi-diameter of the circle is 15′ 45″.

sun's image so that it can be centered very accurately on the sun's disc. When this reticule is used, the pointings are more accurate than when the sun's image is brought tangent to the cross lines. In addition, the difficulty of choosing the correct quadrants is eliminated, and there is no danger that a stadia line might be used in error.

Make three pointings with the telescope direct and three with the telescope reversed, without moving the circle and therefore without using the lower motion. Read the *A* vernier and the vertical angle vernier both to the nearest vernier division at each pointing. Record the time of the first and last pointings. Finally sight mark B with the telescope reversed and read the *A* vernier. It should read 180° within ± 1 minute. Add ± 180° to all reversed pointings.

Find the averages respectively of the horizontal readings, the vertical readings, and the time. Correct the horizontal readings by the average of the two readings on the mark B. Take the air temperature or estimate it.

31. Computation. Formula for machine computation.*

$$\cos Z = \frac{\sin d - \sin h \sin l}{\cos h \cos l} \quad \ldots\ldots (7)$$

Formula for logarithmic computation.*

$$\cos Z = \frac{\sin d}{\cos h \cos l} - \tan h \tan l$$

where Z (Sec. 15) is the sun's bearing. It may be greater than 90°. A minus value of $\cos Z$ indicates a value of Z greater than 90°. If the observation was taken in the morning the bearing is east of north and vice versa. d (Sec. 17) is the declination taken from Table 1, to the nearest 0.1′. h (Sec. 20) is the measured altitude to the nearest 0.1′ corrected for refraction and parallax. l is the latitude to the nearest 0.1′ taken from the map.

Five place tables give sufficient accuracy.

32. Example. Assume latitude (from map) N38° 10.1′, temperature 70° F., elevation 600 ft., the field notes are: Date: May 6, 1963

All horizontal angles clockwise.
Watch on Central Time.

Transit at A, Pointing	B at start	0° 00′
	B at end	0° 00′
	Correction	0° 00′

Pointing Sun

	Hor. Ang.	Vert. Ang.	Time
Direct	157° 54.0′	33° 48.0′	3:40 PM
	158° 10.5′	33° 26.5′	
	158° 23.0′	33° 12.0′	
Reversed	159° 05.5′	32° 50.0′	
	159° 18.0′	32° 31.0′	
	159° 34.0′	32° 09.0′	3:50 PM
Aver.	158° 44.2′	32° 59.4′	3:45 PM
Correction	0.0		
	158° 44.2′		

* If frequent Sun Observations are made, special trigonometric tables that readily solve this formula are available in the booklet "Shoot the Sun", published by State Publishing Co., Helena, Mont.

Standard time 90th meridian	3:45 PM
Correction for 24 hour basis	+ 12
90th meridian time	15:45
Correction for time zone	+ 6
GCT (Sec. 5)	21:45
Sun's d 0^h May 6, 1963 (Table 1)	+16° 16.2′
Change since 0^h; 21.75 × 0.70	+ 15.2
Sun's d	+16° 31.4′
Measured altitude	32° 59.4′
Refraction and parallax (Table 2)	
$-(1.48)\ (.96)\ (.99) + .13 =$	− 1.3
True altitude, h	32° 58.1′

$$\cos Z = \frac{\sin 16° 31.4' - \sin 32° 58.1' \sin 38° 10.1'}{\cos 32° 58.1' \cos 38° 10.1'}$$

$$\cos Z = \frac{(.28440) - (.54418)\ (.61797)}{(.83897)\ (.78620)}$$

$$\cos Z = -\ .07867$$

$$Z = 94° 30.7'$$

See Fig. 2.

Sun's bearing	S 85° 29.3′ W
Clockwise angle B to sun	158° 44.2′
Bearing of mark B	S 73° 14.9′ E

33. Use in Southern Hemisphere. The formula can be used without change for observations in the southern hemisphere. South latitude as well as south declination must be taken as minus. Z will be measured from the north, as before.

METHOD 4. BY USE OF THE SOLAR ATTACHMENT

34. Description. By use of the solar attachment, the transit can be made to solve the astronomical triangle automatically. Thus, by direct observation of the sun, the line of sight can be brought into the plane of the local meridian. The accuracy is limited to about ± 2 minutes.

III. THE DETERMINATION OF LATITUDE

35. Description. The latitude of the point of observation is required for several methods of determining a true bearing. For these observations, when it cannot be accurately determined from a map, latitude must be determined in the field.

Latitude can be determined, without accurate time and independent of other observations, by measuring the altitude of the sun or a star when it reaches its culmination.

Directions for Observation. The instrument must be in good adjustment. Choose a time when any star, or the sun, is approaching a point north or south of the point of observation. Follow the body with the cross lines to the point of maximum (or minimum) altitude.* When this point is reached, stop moving the cross lines and record the altitude.

Computation. The observed altitude is corrected for refraction (and for semi-diameter and parallax if the sun is observed) and the zenith distance (Sec. 20) is derived from it. The formulas used are the following:

$$z = 90° - h \quad \ldots\ldots\ldots\ldots (8)$$

Then at upper culmination $l = d + z \ldots\ldots (9)$

at lower culmination $l = (180° - d) + z$
where l is the latitude, d is the declination (Sec. 3) and z the zenith distance. The signs

*A maximum occurs at *upper culmination*, a minimum at *lower culmination*. Lower culmination can be observed only on bodies having a declination which, when added to the latitude of the observer, gives a value numerically larger than 90°.

of each of these terms must be carefully taken into account as follows:

South latitudes are minus.

South declinations are minus.

Zenith distances of bodies north of the observer are minus in both north and south hemispheres.

Note: In Eq. 9 the parenthesis $(180° - d)$ is computed as though d were plus. The result is then given the actual sign of d.

One of the twenty seven stars for which data are available passes the meridian nearly every hour. (See Fig. 10. For identification see Sec. IV.) It is unnecessary, therefore, to predetermine when the observation must be made. If it is desired to observe Polaris or the sun, it is convenient to estimate the proper time to make the observation. The time of upper or lower culmination of Polaris can be estimated from Fig. 5. The time of upper culmination of the sun is noon, True Solar Time. It is estimated as follows, when approximate longitude is available:

$$\begin{aligned} GCT \text{ of True Solar Noon} \\ &= 12 \text{ hours} + \text{West Longitude} \\ &\quad - \text{Equation of Time} \end{aligned} \tag{10}$$

Example of estimating the time of the sun's upper culmination. Assume longitude approximately W102°; observation to be made May 6, 1963.

Noon, True Solar Time	12.0 hrs.
Less equation of time (Sec. 8) Table 1	− 0.1
LCT	11.9
Add W. Long. converted to hours (Sec. 5) $\frac{102}{15} =$	+ 6.8
GCT (Sec. 8) of True Solar Noon at W102°	18.7
Zone Correction to Mountain Time (105th meridian)	− 7.0
Mountain time	11.7

Example of a sun observation. Assume that the observation described above resulted in the following observed altitude of the sun's upper limb (top), temperature 50° F., barometer 29.6 in.

Observed altitude		58° 29.7′
Refraction and parallax cor. (Table 2) − 0.59 + 0.07		− 0.5
Altitude upper limb		58° 29.2′
Less sun's semi-diameter May 6, 1963 (Table 4)		− 15.9
True altitude h		58° 13.3′
$z = 90 - h$ (z is taken as plus when body is south of observer)		+31° 46.7′
Sun's d 0^h May 6, 1963 (Table 1)	+16° 16.2′	
Change since 0^h; 18.7 × .70	+ 13.1	
Sun's d		+16° 29.3′
Latitude		+48° 16.0′

Example of a Polaris observation. Assume observation on Polaris at lower culmination May 6, 1963; temperature 50°; elevation 1000 ft.; observed altitude 35° 21.9′.

Observed Altitude	35° 21.9′
Refraction correction (Table 2) − 1.35 × 1.00 × 0.98	− 1.3
True altitude, h	35° 20.6′
$z = 90 - h$ (z is taken as minus when body is north of observer)	−54° 39.4′
Polaris d May 6, 1963 (Table 3). 90° − 0° 54.6′ = + 89° 05.4′. 180° − d (lower cul.)	+90° 54.6′
Latitude	+36° 15.2′

IV. SUPPLEMENTARY OBSERVATIONS

Since K&E surveying instruments are used in many parts of the world where Polaris cannot be observed and other difficulties are encountered, this supplement has been prepared to cover the usual problems faced. It includes methods of determining a true bearing by observing stars other than Polaris, and by observations on Polaris at any time when accurate time and longitude are unavailable. To complete the description of celestial observations, it also gives a method of determining longitude.

Identification. Fig. 10 is arranged to show the appearance of the heavens. The declinations are marked along the edges. The declination which is directly above the observer is equal to the latitude. Hours are marked from 0 to 24 along the bottom. The hour line, which is overhead at any time, can be found by Fig. 5 or computed from the following formula: Hour line overhead = local PM time + 2 × (number of months since March 22) . . (11)

For example; at 10 PM on December 4, the hour line overhead is $10 + 2 \times 8.4 = 26.8$. Rejecting 24 hours, this gives 2.8 or nearly 3 hours.

Data Available in this Booklet. The necessary data are available in this booklet for twenty six stars. The stars are shown in Fig. 10 and the data are listed in Table 13. Certain terms, not always familiar to engineers, are used. They are illustrated in Fig. 11.

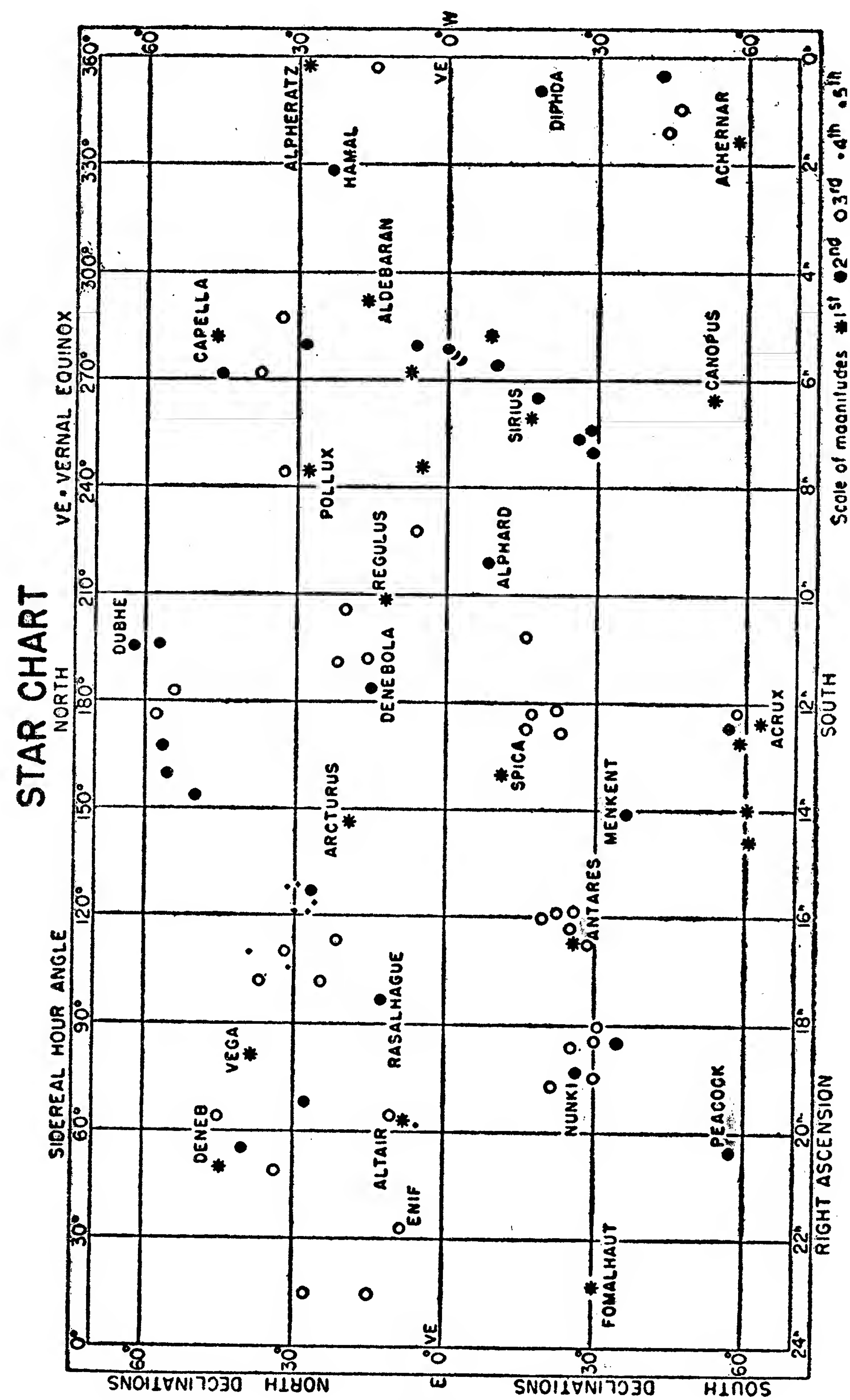
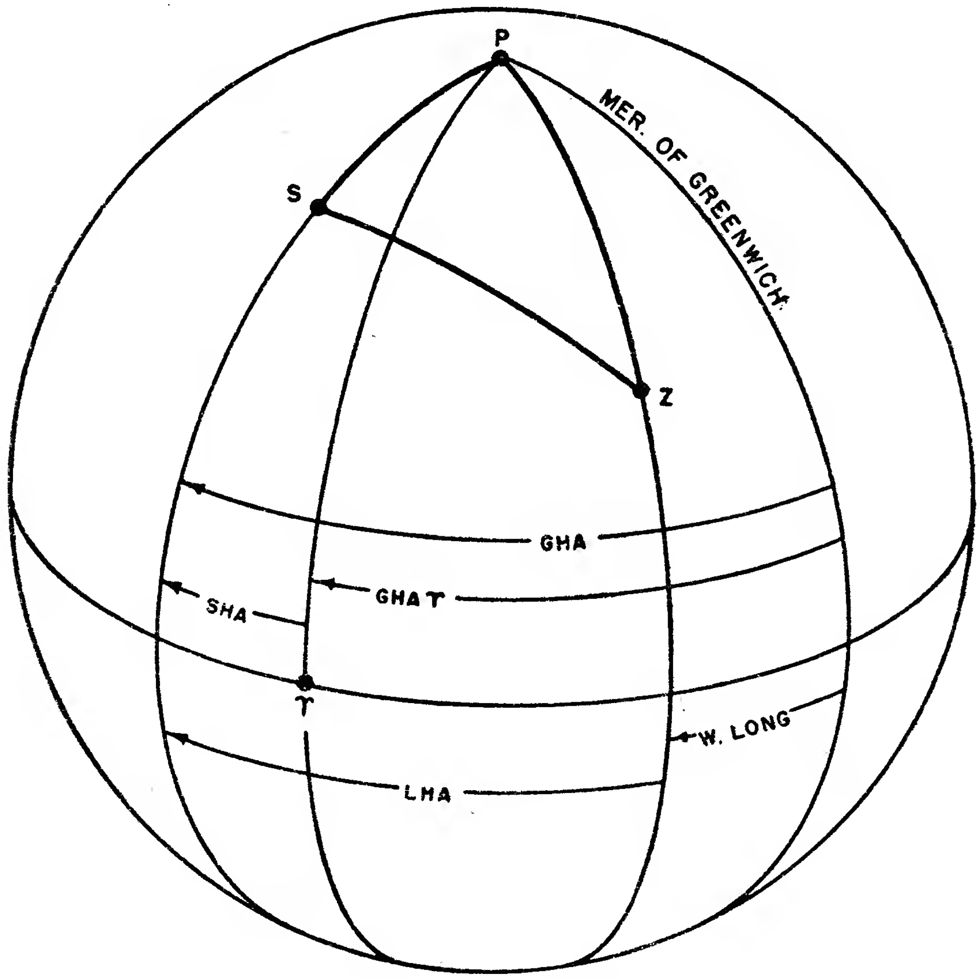

STAR CHART
NORTH
SOUTH
VE = VERNAL EQUINOX
SIDEREAL HOUR ANGLE
RIGHT ASCENSION
NORTH DECLINATIONS
SOUTH DECLINATIONS
W
E
DUBHE
CAPELLA
ALPHERATZ
HAMAL
ALDEBARAN
POLLUX
REGULUS
DENEBOLA
ARCTURUS
VEGA
DENEB
RASALHAGUE
ALTAIR
ENIF
SIRIUS
ALPHARD
SPICA
MENKENT
ANTARES
NUNKI
FOMALHAUT
DIPHDA
ACHERNAR
CANOPUS
ACRUX
PEACOCK
Scale of magnitudes * 1st ● 2nd ○ 3rd • 4th · 5th

Fig. 10.



GHA = GHA♈ + SHA
LHA = GHA − W. LONG

Fig. 11.

♈ represents the Vernal Equinox. It is a certain point on the equator of the celestial sphere that has been chosen as a reference point.

*SHA** (The Sidereal Hour Angle of the body observed) is the angle measured westward from the Vernal Equinox to the body's celestial meridian. Since all the heavenly bodies change their positions on the celestial sphere very slowly, the *SHA* of any star changes only very slowly with time.

* *SHA* = 360° — Right Ascension (expressed in degrees)

GHA ♈ (The Greenwich Hour Angle of the Vernal Equinox) is the angle, at the moment of observation, measured from the Greenwich meridian westward to the Vernal Equinox.

Obviously, the *GHA* of any celestial body is determined from the following formula:

$$GHA = SHA + GHA \ ♈$$

Table 13 gives the *SHA* and the declination of each of twenty-six stars at the first of each month throughout the year. Under each month is listed a correction. The correction for the date of observation should be interpolated and added algebraically to the *SHA* or Decl. given at the left.

Example. To find the declination of Acrux on Apr. 17, 1963.

(Decl.)	S 62° 53′
Correction (interpolated)	+ 0.8
	S 62° 53.8′

Table 12 gives the *GHA* of ♈ for each date at 0^h *GCT*. By using Table 5, the *GHA* can be brought up to the moment at which the observation was made.

Example. To find the *GHA* of Aldebaran on Jan. 3, 1963, at 2:31:48 *GCT*.

From Table 13, *SHA*	291° 33.0′
GHA ♈ 0^h Jan.3,1963 (Table 12)	101° 53.8′
Correction for 2^h31^m (Table 5)	37 51.2
Correction for 48^s (Table 5)	12.0
GHA (sum, rejecting 360°)	71° 30.0′

TRUE BEARING WITHOUT POLARIS

Description. In high northern latitudes, when Polaris is too near the zenith to be observed, and in southern latitudes where Polaris

cannot be seen, the most accurate method of determining a true bearing is by observations of the altitudes of stars.

The method consists of simultaneously observing the horizontal angle from a mark to a star and the star's altitude. The procedure for this operation is the same as that for finding true north by the altitude of the sun as described on page 142. Each observation consists of six direct and six reversed pointings with the horizontal circle in the same position. Time does not have to be recorded, as the declinations of the stars do not change rapidly enough to make it necessary. The method is not very accurate, especially in high latitudes, and therefore many observations must be taken. The stars chosen should be nearly on the ***prime vertical***, that is, nearly east or west from the observer and preferably 25° to 30° above the horizon. They should be observed in pairs, one east and one west, at about the same altitude. This process eliminates the effect of errors in estimating refraction.

Directions for Observation. Choose two bright stars, one in the east and one in the west, at altitudes of about 25° to 30°. Unless they can be immediately recognized, make sketches showing the positions of the stars that surround them, to aid in later identification. Complete several observations of each star, alternating between the two.

To identify the stars, find the point in the chart which was overhead during the observation. Three to five hours east and west from this point, and slightly toward the equator, are the parts of the sky where the stars observed will be found. Identify them from the sketches. Any bright, unwinking body not shown on the chart is probably a planet. Planets require special corrections.

Computations. The computations for one star are shown. Those for other stars are similar. Use the formula given on page 146. (Eq. 7). In this case Z (Sec. 15) is the star's true bearing from the north. Assume, star observed NUNKI (in east), June 3, 1963; latitude S40° 20′ (from map), clockwise horizontal angle from mark B to star, 125° 10′; vertical angle 35° 55.7′, temperature 40°, barometer 28.1 inches.

d Nunki June 3, 1963 (Table 13)	−26° 20.5′
Measured altitude	35 55.7
Refraction correction (Sec. 21) (Table 2) $-1.32 \times 1.02 \times .95 =$	− 1.3
True altitude, h (Sec. 20)	35° 54.4′

$$\cos Z = \frac{\sin(-26°20.5') - \sin(35°54.4')\sin(-40°20.0')}{\cos 35°54.4' \cos(-40°20.0')}$$

$$\cos Z = \frac{(-.44372) - (.58647)\,(-.64723)}{(.80997)\,(.76229)}$$

$$\cos Z = -0.10388$$

$$Z = 95°\ 57.8'$$

Star's bearing (Sec. 14)	S 84° 02.2′ E
Clockwise angle B to star	125° 10.0′
Bearing mark B	N 29° 12.2′ W

True Bearing by a Southern Circumpolar Star. Stars that are near the poles are called circumpolar stars. In the southern hemisphere the nearest bright star to the pole is about 30° distant from it. Several such stars exist, and an observation for true bearing can be made on one of them in exactly the same way as the observation on Polaris, which is made in the northern hemisphere. The field work is identical. The computation must be based on the following formula:

$$\tan Z = \frac{\sin t}{\cos l \cot p - \sin l \cos t} \quad . . (11)$$

Whichever star is nearest elongation (Sec. 23) should be chosen. A star that is on an hour line about 6 hours from the overhead position is nearly at elongation.

OBSERVATION TO DETERMINE t

When an observation is made on Polaris or on a southern circumpolar star, if either longitude, accurate time, or both, are unavailable, the angle t of the circumpolar can be found by an observation on a star near the prime vertical, as follows:

Observe the altitude and take the time of each pointing. The horizontal angle is not required. Using the average altitude corrected for refraction and the average time, compute angle t for the east west star by the following formula:

$$\cos t = \frac{\sin h - \sin d \sin l}{\cos d \cos l} \quad \ldots\ldots (12)$$

Since the *SHA* of each star is given in table 13 the difference between *SHA*'s can be computed. The difference in t is the same as the difference in *SHA*. Thus if the value of t for the east west star at the time of the observation is known, the value of t for the circumpolar at that moment can be computed by applying the difference of the *SHA*'s. The change in t that occurred between the times of the two observations can be computed by Table 5.

The *SHA* of Polaris is not given in Table 13. To find it, use the equation:

$$SHA = GHA - GHA\ \Upsilon.$$

Example. Assume that neither longitude nor time had been available for the example given in Sec. 27, and that instead, the star Pollux had been observed in the west. *Required to obtain* ***t*** *of Polaris.*

Time of observation of Polaris May 5, 1963; 8:49:47 PM (approx. C. S. T.); latitude N42° 22.6′ by method in Sec. III.

Time of observation of Pollux 9:10:04 (by the same watch); measured altitude 40° 11.0′; temperature 60°; barometer 29.8 inches.

In the formula given above, h is the altitude corrected for refraction, d is the declination of

east or west star taken from Table 13, l is the latitude. All are taken to the nearest 0.1′. Five places of decimals is sufficient.

Measured altitude	40° 11.0′
Less refraction correction (Table 2)	
$-1.14 \times .98 \times 1.01$	− 1.1′
True altitude h	40° 09.9′

$$\cos t = \frac{\sin 40° 09.9' - \sin 28° 07.0' \sin 42° 22.6'}{\cos 28° 07.0' \cos 42° 22.6'}$$

$$\cos t = \frac{.64499 - (.47127)(.67400)}{(.88199)\ (.73873)}$$

$\cos t = .50242$

$t = 59°\ 50.4'$ (Pollux)

LHA Pollux 59° 50.4′ (see Sec. 14)

1. *GHA* Polaris 0^h *G* May 6, 1963 (Table 1)	193° 55.7′
	360° 00.0′
	553° 55.7′
2. *GHA* ♈ 0^h *G* May 6, 1963 (Table 12)	223° 07.8′
3. *SHA* Polaris all day May 6, 1963, (1) − (2)	330° 47.9′
4. *SHA* Pollux all day May 6, 1963 (Table 13)	244° 14.3′
5. Cor. to be added to *LHA* Pollux to obtain *LHA* Polaris (3) − (4)	86° 33.6′
6. *LHA* Pollux at 9:10:04 by watch (above)	59° 50.4′
7. *LHA* Polaris at 9:10:04 by watch (5) + (6)	146° 24.0′
8. Elapsed time between observations 8:49:47 − 9:10:04 = − 0:20:17	
9. Correction for elapsed time (Table 5)	− 5° 05.1′
10. t for Polaris at 8:49:47 by watch	141° 18.9′

Having obtained t for Polaris the computation for the bearing can be made as before.

TO FIND LONGITUDE

To find longitude except from a map, accurate time must be available. When it is available, an observation such as described for Pollux above will give longitude if the time of each pointing on the star is recorded.

Example. Assume that the correct *GCT* (see Sec. 27 for computation of *GCT*) for the observation of the altitude of Pollux was 2:53:39, May 6, 1963.

SHA Pollux May 6, 1963 (Table 13)	244° 14.3′
GHA ♈ 0^h *G* May 6, 1963 (Table 12)	223° 07.8′
Correction for 2^h 53^m (Table 5)	43° 22.1′
Correction for 39^s (Table 5)	9.8′
GHA Pollux (add four above)	510° 54.0′
Rejecting 360°	150° 54.0′
Less *LHA* as computed	59° 50.4′
West Longitude	91° 03.6′

TABLES

Basic astronomical data for the K&E Solar Ephemeris was furnished by the U. S. Naval Observatory, Washington, D. C.

Electronic data processing was used to compute the various readings of Table 1. The data obtained from the computers was photographed directly from the material as furnished us. Page headings were added prior to printing.

TABLE 1

SOLAR EPHEMERIS JANUARY 1963

For 0^h Universal Time or Greenwich Civil Time

Day of Month & Week		The Sun's Apparent Declination	Diff. in Declin. for 1 hour	Equation of Time: True Sol. Time = LCT + Eq. of Time	Equation of Time: Differ. for 1 hour	GHA of Polaris
		° ′	′	m s	s	° ′
01	TU	S23 04.7	0.20	− 3 07.8	1.19	70 18.1
02	W	S22 59.9	0.22	− 3 36.3	1.17	71 17.5
03	TH	S22 54.7	0.24	− 4 04.4	1.16	72 17.0
04	FR	S22 49.0	0.25	− 4 32.2	1.14	73 16.5
05	SA	S22 42.9	0.28	− 4 59.6	1.13	74 15.9
06	SU	S22 36.3	0.29	− 5 26.6	1.10	75 15.3
07	M	S22 29.3	0.31	− 5 53.0	1.09	76 14.7
08	TU	S22 21.9	0.33	− 6 19.1	1.06	77 14.2
09	W	S22 14.0	0.35	− 6 44.6	1.04	78 13.6
10	TH	S22 05.6	0.36	− 7 09.6	1.02	79 13.1
11	FR	S21 56.9	0.38	− 7 34.0	1.00	80 12.6
12	SA	S21 47.7	0.40	− 7 57.9	0.97	81 12.0
13	SU	S21 38.1	0.42	− 8 21.2	0.94	82 11.6
14	M	S21 28.0	0.43	− 8 43.8	0.92	83 11.1
15	TU	S21 17.6	0.45	− 9 05.9	0.89	84 10.6
16	W	S21 06.7	0.47	− 9 27.3	0.87	85 10.1
17	TH	S20 55.4	0.48	− 9 48.1	0.84	86 09.6
18	FR	S20 43.8	0.50	−10 08.2	0.81	87 09.1
19	SA	S20 31.7	0.52	−10 27.6	0.78	88 08.5
20	SU	S20 19.3	0.54	−10 46.3	0.75	89 08.0
21	M	S20 06.4	0.55	−11 04.3	0.72	90 07.5
22	TU	S19 53.2	0.57	−11 21.6	0.69	91 06.9
23	W	S19 39.6	0.58	−11 38.1	0.66	92 06.4
24	TH	S19 25.7	0.60	−11 53.9	0.62	93 05.8
25	FR	S19 11.4	0.61	−12 08.8	0.59	94 05.3
26	SA	S18 56.7	0.63	−12 23.0	0.56	95 04.8
27	SU	S18 41.7	0.64	−12 36.4	0.53	96 04.4
28	M	S18 26.4	0.65	−12 49.0	0.49	97 03.9
29	TU	S18 10.7	0.67	−13 00.7	0.46	98 03.4
30	W	S17 54.7	0.68	−13 11.7	0.42	99 03.0
31	TH	S17 38.4	0.70	−13 21.7	0.39	100 02.4
32	FR	S17 21.7		−13 31.0		101 01.9

TABLE 1
SOLAR EPHEMERIS FEBRUARY 1963
For O^h Universal Time or Greenwich Civil Time

Day of Month & Week		The Sun's Apparent Declination		Diff. in Declin. for 1 hour	Equation of Time: True Sol. Time = LCT + Eq. of Time		Equation of Time: Differ. for 1 hour	GHA of Polaris	
		°	′	′	m	s	s	°	′
01	FR	S17	21.7	0.70	−13	31.0	0.35	101	01.9
02	SA	S17	04.8	0.72	−13	39.4	0.32	102	01.4
03	SU	S16	47.6	0.73	−13	47.0	0.28	103	00.8
04	M	S16	30.0	0.74	−13	53.7	0.25	104	00.3
05	TU	S16	12.2	0.75	−13	59.6	0.21	104	59.7
06	W	S15	54.1	0.77	−14	04.7	0.18	105	59.2
07	TH	S15	35.7	0.78	−14	08.9	0.15	106	58.7
08	FR	S15	17.1	0.79	−14	12.4	0.11	107	58.2
09	SA	S14	58.2	0.80	−14	15.0	0.08	108	57.7
10	SU	S14	39.1	0.81	−14	16.9	0.05	109	57.2
11	M	S14	19.7	0.82	−14	18.0	0.01	110	56.7
12	TU	S14	00.0	0.83	−14	18.3	0.02	111	56.2
13	W	S13	40.2	0.84	−14	17.8	0.05	112	55.7
14	TH	S13	20.1	0.85	−14	16.7	0.08	113	55.1
15	FR	S12	59.8	0.85	−14	14.7	0.11	114	54.6
16	SA	S12	39.3	0.87	−14	12.1	0.14	115	54.0
17	SU	S12	18.5	0.87	−14	08.8	0.17	116	53.5
18	M	S11	57.6	0.88	−14	04.7	0.20	117	52.9
19	TU	S11	36.5	0.89	−14	00.0	0.23	118	52.3
20	W	S11	15.2	0.90	−13	54.6	0.25	119	51.7
21	TH	S10	53.7	0.90	−13	48.6	0.28	120	51.2
22	FR	S10	32.1	0.91	−13	41.9	0.30	121	50.6
23	SA	S10	10.3	0.92	−13	34.6	0.33	122	50.1
24	SU	S 9	48.3	0.92	−13	26.7	0.36	123	49.6
25	M	S 9	26.2	0.93	−13	18.1	0.38	124	49.1
26	TU	S 9	04.0	0.93	−13	09.0	0.41	125	48.5
27	W	S 8	41.6	0.94	−12	59.2	0.43	126	48.0
28	TH	S 8	19.1	0.95	−12	48.9	0.45	127	47.4
29	FR	S 7	56.4		−12	38.1		128	46.8

TABLE 1

SOLAR EPHEMERIS MARCH 1963

For 0^h Universal Time or Greenwich Civil Time

Day of Month	& Week	The Sun's Apparent Declination	Diff. in Declin. for 1 hour	Equation of Time: True Sol. Time = LCT + Eq. of Time	Equation of Time: Differ. for 1 hour	GHA of Polaris
		° ′	′	m s	s	° ′
01	FR	S 7 56.4		−12 38.1		128 46.8
			0.95		0.48	
02	SA	S 7 33.7		−12 26.6		129 46.1
			0.95		0.50	
03	SU	S 7 10.8		−12 14.7		130 45.5
			0.96		0.52	
04	M	S 6 47.8		−12 02.2		131 44.9
			0.96		0.54	
05	TU	S 6 24.8		−11 49.3		132 44.2
			0.97		0.56	
06	W	S 6 01.6		−11 35.9		133 43.6
			0.97		0.58	
07	TH	S 5 38.4		−11 22.0		134 43.0
			0.97		0.59	
08	FR	S 5 15.1		−11 07.8		135 42.4
			0.97		0.61	
09	SA	S 4 51.8		−10 53.1		136 41.8
			0.98		0.63	
10	SU	S 4 28.3		−10 38.0		137 41.3
			0.98		0.64	
11	M	S 4 04.9		−10 22.6		138 40.7
			0.98		0.65	
12	TU	S 3 41.3		−10 06.9		139 40.0
			0.98		0.67	
13	W	S 3 17.7		− 9 50.8		140 39.4
			0.98		0.68	
14	TH	S 2 54.1		− 9 34.5		141 38.8
			0.98		0.69	
15	FR	S 2 30.5		− 9 17.9		142 38.1
			0.99		0.70	
16	SA	S 2 06.8		− 9 01.1		143 37.4
			0.99		0.71	
17	SU	S 1 43.1		− 8 44.0		144 36.7
			0.99		0.72	
18	M	S 1 19.4		− 8 26.8		145 36.0
			0.99		0.73	
19	TU	S 0 55.7		− 8 09.4		146 35.3
			0.99		0.73	
20	W	S 0 31.9		− 7 51.8		147 34.6
			0.99		0.74	
21	TH	S 0 08.2		− 7 34.1		148 33.9
			0.99		0.75	
22	FR	N 0 15.5		− 7 16.2		149 33.3
			0.99		0.75	
23	SA	N 0 39.2		− 6 58.3		150 32.6
			0.98		0.75	
24	SU	N 1 02.8		− 6 40.3		151 31.9
			0.99		0.75	
25	M	N 1 26.5		− 6 22.3		152 31.3
			0.98		0.75	
26	TU	N 1 50.1		− 6 04.2		153 30.6
			0.98		0.76	
27	W	N 2 13.7		− 5 46.0		154 29.9
			0.98		0.76	
28	TH	N 2 37.2		− 5 27.8		155 29.1
			0.98		0.75	
29	FR	N 3 00.6		− 5 09.7		156 28.3
			0.98		0.76	
30	SA	N 3 24.1		− 4 51.5		157 27.5
			0.97		0.75	
31	SU	N 3 47.4		− 4 33.4		158 26.7
			0.97		0.75	
32	M	N 4 10.7		− 4 15.4		159 26.0

TABLE 1

SOLAR EPHEMERIS APRIL 1963

For O^h Universal Time or Greenwich Civil Time

Day of Month & Week		The Sun's Apparent Declination	Diff. in Declin. for 1 hour	Equation of Time: True Sol. Time = LCT + Eq. of Time	Equation of Time: Differ. for 1 hour	GHA of Polaris
		° ′	′	m s	s	° ′
01	M	N 4 10.7		− 4 15.4		159 26.0
02	TU	N 4 33.9	0.97	− 3 57.4	0.75	160 25.2
03	W	N 4 57.0	0.96	− 3 39.5	0.75	161 24.4
04	TH	N 5 20.0	0.96	− 3 21.7	0.74	162 23.7
05	FR	N 5 42.9	0.95	− 3 04.0	0.74	163 22.9
06	SA	N 6 05.7	0.95	− 2 46.5	0.73	164 22.2
07	SU	N 6 28.4	0.95	− 2 29.2	0.72	165 21.4
08	M	N 6 51.0	0.94	− 2 12.1	0.71	166 20.6
09	TU	N 7 13.5	0.94	− 1 55.2	0.70	167 19.8
10	W	N 7 35.9	0.93	− 1 38.5	0.70	168 19.0
11	TH	N 7 58.1	0.93	− 1 22.1	0.68	169 18.2
12	FR	N 8 20.2	0.92	− 1 05.9	0.68	170 17.3
13	SA	N 8 42.2	0.92	− 0 50.1	0.66	171 16.5
14	SU	N 9 04.0	0.91	− 0 34.6	0.65	172 15.6
15	M	N 9 25.6	0.90	− 0 19.4	0.63	173 14.7
16	TU	N 9 47.2	0.90	− 0 04.6	0.62	174 13.9
17	W	N10 08.5	0.89	0 09.9	0.60	175 13.0
18	TH	N10 29.7	0.88	0 24.0	0.59	176 12.2
19	FR	N10 50.7	0.88	0 37.7	0.57	177 11.3
20	SA	N11 11.5	0.87	0 50.9	0.55	178 10.5
21	SU	N11 32.2	0.86	1 03.7	0.53	179 09.7
22	M	N11 52.7	0.85	1 16.1	0.52	180 08.8
23	TU	N12 12.9	0.84	1 28.1	0.50	181 07.9
24	W	N12 33.0	0.84	1 39.6	0.48	182 07.0
25	TH	N12 52.9	0.83	1 50.6	0.46	183 06.1
26	FR	N13 12.5	0.82	2 01.2	0.44	184 05.1
27	SA	N13 32.0	0.81	2 11.3	0.42	185 04.1
28	SU	N13 51.2	0.80	2 20.9	0.40	186 03.2
29	M	N14 10.2	0.79	2 30.0	0.38	187 02.2
30	TU	N14 28.9	0.78	2 38.7	0.36	188 01.3
31	W	N14 47.4	0.77	2 46.8	0.34	189 00.3

TABLE I
SOLAR EPHEMERIS MAY 1963
For 0^h Universal Time or Greenwich Civil Time

Day of Month	& Week	The Sun's Apparent Declination	Diff. in Declin. for 1 hour	Equation of Time: True Sol. Time = LCT + Eq. of Time	Equation of Time: Differ. for 1 hour	GHA of Polaris
		° ′	′	m s		° ′
01	W	N14 47.4	0.76	2 46.8	0.32	189 00.3
02	TH	N15 05.7	0.75	2 54.4	0.30	189 59.4
03	FR	N15 23.7	0.74	3 01.5	0.28	190 58.5
04	SA	N15 41.4	0.73	3 08.1	0.25	191 57.6
05	SU	N15 58.9	0.72	3 14.1	0.23	192 56.6
06	M	N16 16.2	0.70	3 19.6	0.21	193 55.7
07	TU	N16 33.1	0.70	3 24.6	0.18	194 54.7
08	W	N16 49.8	0.68	3 28.9	0.16	195 53.7
09	TH	N17 06.2	0.67	3 32.8	0.13	196 52.7
10	FR	N17 22.3	0.66	3 36.0	0.11	197 51.6
11	SA	N17 38.1	0.65	3 38.7	0.09	198 50.6
12	SU	N17 53.7	0.63	3 40.8	0.06	199 49.6
13	M	N18 08.9	0.62	3 42.3	0.04	200 48.5
14	TU	N18 23.8	0.61	3 43.2	0.01	201 47.5
15	W	N18 38.4	0.60	3 43.5	0.01	202 46.5
16	TH	N18 52.8	0.58	3 43.3	0.04	203 45.5
17	FR	N19 06.7	0.57	3 42.4	0.06	204 44.5
18	SA	N19 20.4	0.55	3 41.0	0.08	205 43.5
19	SU	N19 33.7	0.55	3 39.0	0.11	206 42.5
20	M	N19 46.8	0.53	3 36.4	0.13	207 41.5
21	TU	N19 59.4	0.52	3 33.3	0.15	208 40.4
22	W	N20 11.8	0.50	3 29.6	0.18	209 39.3
23	TH	N20 23.7	0.49	3 25.4	0.20	210 38.2
24	FR	N20 35.4	0.47	3 20.6	0.22	211 37.1
25	SA	N20 46.7	0.45	3 15.3	0.24	212 35.9
26	SU	N20 57.6	0.44	3 09.6	0.26	213 34.8
27	M	N21 08.2	0.43	3 03.3	0.28	214 33.7
28	TU	N21 18.4	0.41	2 56.6	0.30	215 32.7
29	W	N21 28.2	0.40	2 49.4	0.32	216 31.6
30	TH	N21 37.7	0.38	2 41.8	0.33	217 30.6
31	FR	N21 46.7	0.36	2 33.8	0.35	218 29.5
32	SA	N21 55.4		2 25.4		219 28.4

TABLE 1

SOLAR EPHEMERIS JUNE 1963

For 0h Universal Time or Greenwich Civil Time

Day of Month	& Week	The Sun's Apparent Declination °	′	Diff. in Declin. for 1 hour ′	Equation of Time: True Sol. Time = LCT + Eq. of Time m	s	Equation of Time: Differ. for 1 hour s	GHA of Polaris °	′
01	SA	N21	55.4	0.35	2	25.4	0.37	219	28.4
02	SU	N22	03.8	0.33	2	16.5	0.38	220	27.3
03	M	N22	11.7	0.32	2	07.3	0.40	221	26.2
04	TU	N22	19.3	0.30	1	57.7	0.41	222	25.1
05	W	N22	26.4		1	47.8		223	23.9
06	TH	N22	33.2	0.28	1	37.5	0.43	224	22.8
07	FR	N22	39.6	0.27	1	26.9	0.44	225	21.6
08	SA	N22	45.5	0.25	1	16.0	0.45	226	20.4
09	SU	N22	51.1	0.23	1	04.8	0.47	227	19.3
10	M	N22	56.3	0.22	0	53.3	0.48	228	18.1
11	TU	N23	01.0	0.20	0	41.6	0.49	229	17.0
12	W	N23	05.4	0.18	0	29.7	0.50	230	15.9
13	TH	N23	09.4	0.17	0	17.5	0.51	231	14.8
14	FR	N23	12.9	0.15	0	05.1	0.52	232	13.7
15	SA	N23	16.1	0.13	− 0	07.5	0.53	233	12.5
16	SU	N23	18.8	0.11	− 0	20.2	0.53	234	11.4
17	M	N23	21.1	0.10	− 0	33.1	0.54	235	10.3
18	TU	N23	23.0	0.08	− 0	46.0	0.54	236	09.1
19	W	N23	24.5	0.06	− 0	59.1	0.55	237	07.9
20	TH	N23	25.6	0.05	− 1	12.2	0.55	238	06.6
21	FR	N23	26.3	0.03	− 1	25.3	0.55	239	05.4
22	SA	N23	26.6	0.01	− 1	38.5	0.55	240	04.2
23	SU	N23	26.4	0.01	− 1	51.6	0.55	241	03.0
24	M	N23	25.9	0.02	− 2	04.6	0.54	242	01.9
25	TU	N23	24.9	0.04	− 2	17.6	0.54	243	00.7
26	W	N23	23.5	0.06	− 2	30.4	0.53	243	59.6
27	TH	N23	21.7	0.08	− 2	43.2	0.53	244	58.4
28	FR	N23	19.5	0.09	− 2	55.7	0.52	245	57.2
29	SA	N23	16.8	0.11	− 3	08.1	0.52	246	56.1
30	SU	N23	13.8	0.13	− 3	20.2	0.50	247	54.9
31	M	N23	10.4	0.14	− 3	32.1	0.50	248	53.7

TABLE 1
SOLAR EPHEMERIS JULY 1963
For 0h Universal Time or Greenwich Civil Time

Day of Month & Week		The Sun's Apparent Declination ° ′	Diff. in Declin. for 1 hour ′	Equation of Time: True Sol. Time = LCT + Eq. of Time m s	Equation of Time: Differ. for 1 hour s	GHA of Polaris ° ′
01	M	N23 10.4		− 3 32.1		248 53.7
02	TU	N23 06.5	0.16	− 3 43.8	0.49	249 52.5
03	W	N23 02.3	0.18	− 3 55.2	0.48	250 51.3
04	TH	N22 57.6	0.20	− 4 06.3	0.46	251 50.0
05	FR	N22 52.6	0.21	− 4 17.1	0.45	252 48.8
06	SA	N22 47.1	0.23	− 4 27.5	0.43	253 47.6
07	SU	N22 41.3	0.24	− 4 37.7	0.43	254 46.4
08	M	N22 35.0	0.26	− 4 47.4	0.40	255 45.2
09	TU	N22 28.4	0.28	− 4 56.8	0.39	256 44.0
10	W	N22 21.4	0.29	− 5 05.8	0.38	257 42.8
11	TH	N22 14.0	0.31	− 5 14.5	0.36	258 41.7
12	FR	N22 06.2	0.33	− 5 22.7	0.34	259 40.5
13	SA	N21 58.0	0.34	− 5 30.4	0.32	260 39.3
14	SU	N21 49.5	0.35	− 5 37.8	0.31	261 38.1
15	M	N21 40.6	0.37	− 5 44.6	0.28	262 36.9
16	TU	N21 31.3	0.39	− 5 51.1	0.27	263 35.7
17	W	N21 21.6	0.40	− 5 57.0	0.25	264 34.4
18	TH	N21 11.6	0.42	− 6 02.4	0.23	265 33.2
19	FR	N21 01.3	0.43	− 6 07.3	0.20	266 31.9
20	SA	N20 50.5	0.45	− 6 11.7	0.18	267 30.7
21	SU	N20 39.4	0.46	− 6 15.6	0.16	268 29.5
22	M	N20 28.0	0.48	− 6 18.9	0.14	269 28.3
23	TU	N20 16.2	0.49	− 6 21.6	0.11	270 27.1
24	W	N20 04.1	0.50	− 6 23.7	0.09	271 25.9
25	TH	N19 51.7	0.52	− 6 25.3	0.07	272 24.8
26	FR	N19 38.9	0.53	− 6 26.2	0.04	273 23.6
27	SA	N19 25.8	0.55	− 6 26.6	0.02	274 22.4
28	SU	N19 12.4	0.56	− 6 26.3	0.01	275 21.2
29	M	N18 58.6	0.58	− 6 25.4	0.04	276 20.0
30	TU	N18 44.6	0.58	− 6 23.9	0.06	277 18.7
31	W	N18 30.2	0.60	− 6 21.7	0.09	278 17.5
32	TH	N18 15.5	0.61	− 6 19.0	0.11	279 16.3

TABLE 1
SOLAR EPHEMERIS AUGUST 1963
For 0^h Universal Time or Greenwich Civil Time

Day of Month	& Week	The Sun's Apparent Declination ° ′	Diff. in Declin. for 1 hour ′	Equation of Time: True Sol. Time = LCT + Eq. of Time m s	Equation of Time: Differ. for 1 hour s	GHA of Polaris ° ′
01	TH	N18 15.5		− 6 19.0		279 16.3
02	FR	N18 00.6	0.62	− 6 15.6	0.14	280 15.0
03	SA	N17 45.3	0.64	− 6 11.6	0.17	281 13.8
04	SU	N17 29.8	0.65	− 6 07.0	0.19	282 12.6
05	M	N17 14.0	0.66	− 6 01.7	0.22	283 11.4
06	TU	N16 57.8	0.68	− 5 55.9	0.24	284 10.3
07	W	N16 41.5	0.68	− 5 49.5	0.27	285 09.1
08	TH	N16 24.8	0.70	− 5 42.5	0.29	286 08.0
09	FR	N16 07.9	0.70	− 5 34.9	0.32	287 06.8
10	SA	N15 50.7	0.72	− 5 26.7	0.34	288 05.6
11	SU	N15 33.3	0.73	− 5 18.0	0.36	289 04.4
12	M	N15 15.6	0.74	− 5 08.7	0.39	290 03.2
13	TU	N14 57.7	0.75	− 4 58.9	0.41	291 02.0
14	W	N14 39.5	0.76	− 4 48.6	0.43	292 00.7
15	TH	N14 21.1	0.77	− 4 37.7	0.45	292 59.5
16	FR	N14 02.5	0.78	− 4 26.3	0.48	293 58.3
17	SA	N13 43.6	0.79	− 4 14.4	0.50	294 57.1
18	SU	N13 24.6	0.79	− 4 01.9	0.52	295 56.0
19	M	N13 05.3	0.80	− 3 49.0	0.54	296 54.8
20	TU	N12 45.8	0.81	− 3 35.6	0.56	297 53.7
21	W	N12 26.1	0.82	− 3 21.6	0.58	298 52.6
22	TH	N12 06.2	0.83	− 3 07.2	0.60	299 51.4
23	FR	N11 46.1	0.84	− 2 52.4	0.62	300 50.3
24	SA	N11 25.9	0.84	− 2 37.0	0.64	301 49.1
25	SU	N11 05.4	0.85	− 2 21.2	0.66	302 47.9
26	M	N10 44.8	0.86	− 2 05.0	0.68	303 46.7
27	TU	N10 24.0	0.87	− 1 48.3	0.70	304 45.6
28	W	N10 03.0	0.88	− 1 31.3	0.71	305 44.4
29	TH	N 9 41.9	0.88	− 1 13.8	0.73	306 43.2
30	FR	N 9 20.7	0.88	− 0 56.0	0.74	307 42.0
31	SA	N 8 59.2	0.90	− 0 37.8	0.76	308 40.9
32	SU	N 8 37.7	0.90	− 0 19.2	0.78	309 39.7

TABLE 1

SOLAR EPHEMERIS SEPTEMBER 1963

For O^h Universal Time or Greenwich Civil Time

Day of Month & Week		The Sun's Apparent Declination ° ′	Diff. in Declin. for 1 hour ′	Equation of Time: True Sol. Time = LCT + Eq. of Time m s	Equation of Time: Differ. for 1 hour	GHA of Polaris ° ′
01	SU	N 8 37.7	0.90	− 0 19.2	0.78	309 39.7
02	M	N 8 16.0	0.91	− 0 00.4	0.80	310 38.6
03	TU	N 7 54.2	0.92	0 18.8	0.81	311 37.5
04	W	N 7 32.2	0.92	0 38.3	0.82	312 36.4
05	TH	N 7 10.1	0.93	0 58.0	0.83	313 35.4
06	FR	N 6 47.9	0.93	1 17.9	0.84	314 34.2
07	SA	N 6 25.6	0.93	1 38.1	0.85	315 33.1
08	SU	N 6 03.2	0.94	1 58.5	0.85	316 32.0
09	M	N 5 40.7	0.94	2 19.0	0.86	317 30.8
10	TU	N 5 18.1	0.95	2 39.7	0.87	318 29.7
11	W	N 4 55.4	0.95	3 00.5	0.87	319 28.5
12	TH	N 4 32.6	0.95	3 21.4	0.88	320 27.4
13	FR	N 4 09.7	0.95	3 42.5	0.88	321 26.3
14	SA	N 3 46.8	0.96	4 03.6	0.88	322 25.2
15	SU	N 3 23.8	0.96	4 24.7	0.89	323 24.1
16	M	N 3 00.7	0.96	4 46.0	0.88	324 23.0
17	TU	N 2 37.6	0.97	5 07.2	0.89	325 22.0
18	W	N 2 14.4	0.97	5 28.5	0.88	326 20.9
19	TH	N 1 51.2	0.97	5 49.7	0.89	327 19.9
20	FR	N 1 27.9	0.97	6 11.0	0.88	328 18.8
21	SA	N 1 04.6	0.97	6 32.2	0.88	329 17.7
22	SU	N 0 41.3	0.98	6 53.3	0.88	330 16.7
23	M	N 0 17.9	0.97	7 14.4	0.88	331 15.6
24	TU	S 0 05.4	0.98	7 35.4	0.87	332 14.5
25	W	S 0 28.8	0.98	7 56.3	0.86	333 13.4
26	TH	S 0 52.2	0.98	8 17.0	0.86	334 12.3
27	FR	S 1 15.6	0.98	8 37.6	0.85	335 11.3
28	SA	S 1 39.0	0.97	8 58.1	0.84	336 10.2
29	SU	S 2 02.3	0.98	9 18.3	0.83	337 09.2
30	M	S 2 25.7	0.97	9 38.3	0.83	338 08.2
31	TU	S 2 49.0		9 58.1		339 07.2

TABLE 1

SOLAR EPHEMERIS OCTOBER 1963

For 0h Universal Time or Greenwich Civil Time

Day of Month	& Week	The Sun's Apparent Declination ° ′	Diff. in Declin. for 1 hour ′	Equation of Time: True Sol. Time = LCT + Eq. of Time m s	Equation of Time: Differ. for 1 hour s	GHA of Polaris ° ′
01	TU	S 2 49.0	0.97	9 58.1	0.81	339 07.2
02	W	S 3 12.3	0.97	10 17.6	0.80	340 06.2
03	TH	S 3 35.6	0.97	10 36.9	0.79	341 05.3
04	FR	S 3 58.8	0.96	10 55.8	0.80	342 04.2
05	SA	S 4 21.9	0.97	11 14.9	0.74	343 03.2
06	SU	S 4 45.1	0.96	11 32.6	0.75	344 02.2
07	M	S 5 08.1	0.96	11 50.5	0.73	345 01.1
08	TU	S 5 31.1	0.95	12 07.9	0.71	346 00.1
09	W	S 5 54.0	0.95	12 25.0	0.69	346 59.1
10	TH	S 6 16.9	0.95	12 41.5	0.67	347 58.1
11	FR	S 6 39.7	0.94	12 57.6	0.65	348 57.1
12	SA	S 7 02.3	0.94	13 13.3	0.63	349 56.1
13	SU	S 7 24.9	0.94	13 28.4	0.61	350 55.2
14	M	S 7 47.4	0.93	13 43.0	0.58	351 54.3
15	TU	S 8 09.8	0.93	13 57.0	0.57	352 53.3
16	W	S 8 32.1	0.92	14 10.6	0.54	353 52.4
17	TH	S 8 54.2	0.92	14 23.5	0.52	354 51.5
18	FR	S 9 16.3	0.91	14 35.9	0.49	355 50.5
19	SA	S 9 38.2	0.90	14 47.7	0.46	356 49.6
20	SU	S 9 59.9	0.90	14 58.8	0.44	357 48.6
21	M	S10 21.5	0.90	15 09.4	0.41	358 47.7
22	TU	S10 43.0	0.89	15 19.3	0.39	359 46.7
23	W	S11 04.3	0.88	15 28.6	0.36	00 45.8
24	TH	S11 25.4	0.87	15 37.2	0.33	01 44.8
25	FR	S11 46.3	0.87	15 45.1	0.30	02 43.9
26	SA	S12 07.1	0.86	15 52.4	0.27	03 43.0
27	SU	S12 27.7	0.85	15 58.9	0.24	04 42.2
28	M	S12 48.1	0.84	16 04.7	0.21	05 41.3
29	TU	S13 08.3	0.83	16 09.8	0.18	06 40.5
30	W	S13 28.3	0.82	16 14.2	0.15	07 39.6
31	TH	S13 48.0	0.82	16 17.8	0.12	08 38.8
32	FR	S14 07.6		16 20.7		09 37.9

TABLE 1
SOLAR EPHEMERIS NOVEMBER 1963
For 0^h Universal Time or Greenwich Civil Time

Day of Month & Week		The Sun's Apparent Declination	Diff. in Declin. for 1 hour	Equation of Time: True Sol. Time = LCT + Eq. of Time	Equation of Time: Differ. for 1 hour	GHA of Polaris
		° ′	′	m s	s	° ′
01	FR	S14 07.6	0.80	16 20.7	0.08	09 37.9
02	SA	S14 26.9	0.80	16 22.7	0.05	10 37.0
03	SU	S14 46.0	0.78	16 24.0	0.02	11 36.1
04	M	S15 04.8	0.78	16 24.4	0.02	12 35.2
05	TU	S15 23.4	0.77	16 24.0	0.05	13 34.3
06	W	S15 41.8	0.75	16 22.8	0.09	14 33.5
07	TH	S15 59.9	0.74	16 20.7	0.12	15 32.6
08	FR	S16 17.7	0.73	16 17.8	0.16	16 31.8
09	SA	S16 35.3	0.72	16 14.0	0.20	17 31.0
10	SU	S16 52.6	0.71	16 09.3	0.23	18 30.3
11	M	S17 09.6	0.70	16 03.8	0.27	19 29.5
12	TU	S17 26.3	0.68	15 57.4	0.30	20 28.7
13	W	S17 42.7	0.67	15 50.2	0.34	21 27.9
14	TH	S17 58.8	0.65	15 42.1	0.38	22 27.1
15	FR	S18 14.5	0.65	15 33.1	0.41	23 26.3
16	SA	S18 30.0	0.63	15 23.3	0.45	24 25.5
17	SU	S18 45.1	0.62	15 12.6	0.48	25 24.7
18	M	S19 00.0	0.60	15 01.2	0.52	26 23.9
19	TU	S19 14.4	0.59	14 48.8	0.55	27 23.1
20	W	S19 28.6	0.57	14 35.7	0.58	28 22.4
21	TH	S19 42.3	0.56	14 21.7	0.61	29 21.6
22	FR	S19 55.7	0.55	14 07.0	0.65	30 20.9
23	SA	S20 08.8	0.53	13 51.5	0.68	31 20.2
24	SU	S20 21.5	0.51	13 35.1	0.71	32 19.5
25	M	S20 33.8	0.50	13 18.1	0.74	33 18.8
26	TU	S20 45.7	0.48	13 00.3	0.78	34 18.1
27	W	S20 57.2	0.47	12 41.7	0.80	35 17.4
28	TH	S21 08.4	0.45	12 22.5	0.83	36 16.7
29	FR	S21 19.1	0.43	12 02.5	0.86	37 16.0
30	SA	S21 29.4	0.41	11 41.8	0.89	38 15.2
31	SU	S21 39.3		11 20.5		39 14.5

TABLE 1

SOLAR EPHEMERIS DECEMBER 1963

For 0h Universal Time or Greenwich Civil Time

Day of Month & Week		The Sun's Apparent Declination ° ′	Diff. in Declin. for 1 hour ′	Equation of Time: True Sol. Time = LCT + Eq. of Time m s	Equation of Time: Differ. for 1 hour s	GHA of Polaris ° ′
01	SU	S21 39.3		11 20.5		39 14.5
			0.40		0.92	
02	M	S21 48.9		10 58.5		40 13.7
			0.38		0.95	
03	TU	S21 57.9		10 35.8		41 13.0
			0.36		0.97	
04	W	S22 06.6		10 12.5		42 12.3
			0.35		1.00	
05	TH	S22 14.9		9 48.6		43 11.7
			0.33		1.02	
06	FR	S22 22.7		9 24.1		44 11.0
			0.31		1.05	
07	SA	S22 30.1		8 59.0		45 10.4
			0.29		1.07	
08	SU	S22 37.0		8 33.4		46 09.8
			0.27		1.09	
09	M	S22 43.5		8 07.3		47 09.2
			0.25		1.11	
10	TU	S22 49.6		7 40.7		48 08.5
			0.23		1.13	
11	W	S22 55.2		7 13.6		49 07.9
			0.21		1.15	
12	TH	S23 00.3		6 46.1		50 07.3
			0.20		1.16	
13	FR	S23 05.0		6 18.2		51 06.6
			0.18		1.18	
14	SA	S23 09.3		5 49.9		52 05.9
			0.16		1.19	
15	SU	S23 13.1		5 21.3		53 05.3
			0.14		1.20	
16	M	S23 16.4		4 52.5		54 04.6
			0.12		1.22	
17	TU	S23 19.3		4 23.3		55 04.0
			0.10		1.22	
18	W	S23 21.6		3 54.0		56 03.4
			0.08		1.23	
19	TH	S23 23.6		3 24.4		57 02.8
			0.06		1.24	
20	FR	S23 25.0		2 54.7		58 02.2
			0.04		1.24	
21	SA	S23 26.0		2 24.9		59 01.7
			0.02		1.24	
22	SU	S23 26.5		1 55.1		60 01.1
			0.00		1.25	
23	M	S23 26.6		1 25.2		61 00.6
			0.02		1.25	
24	TU	S23 26.1		0 55.3		62 00.0
			0.04		1.25	
25	W	S23 25.2		0 25.4		62 59.4
			0.05		1.24	
26	TH	S23 23.9		- 0 04.4		63 58.9
			0.08		1.24	
27	FR	S23 22.0		- 0 34.1		64 58.3
			0.10		1.23	
28	SA	S23 19.7		- 1 03.6		65 57.6
			0.12		1.23	
29	SU	S23 16.9		- 1 33.0		66 57.0
			0.13		1.22	
30	M	S23 13.7		- 2 02.2		67 56.4
			0.15		1.21	
31	TU	S23 10.0		- 2 31.2		68 55.8
			0.18		1.20	
32	W	S23 05.8		- 2 59.9		69 55.3

TABLE 2

REFRACTION AND SUN'S PARALLAX

(To be applied to observed altitudes. See page 131)

Bar. = 29.6 in. Temp. = 50° F

Measured Altitude		Refraction	Sun's Par.	Measured Altitude		Refraction	Sun's Par.
°	′	′	′	°	′	′	′
7	30	6.88	0.15	17	30	3.02	0.14
7	40	6.75	0.15	18	00	2.93	0.14
7	50	6.62	0.15	18	30	2.85	0.14
8	00	6.50	0.15	19	00	2.77	0.14
8	10	6.37	0.15	19	30	2.70	0.14
8	20	6.25	0.15	20	00	2.62	0.14
8	30	6.13	0.15	21	00	2.48	0.14
8	40	6.02	0.15	22	00	2.36	0.14
8	50	5.92	0.15	23	00	2.25	0.14
9	00	5.82	0.15	24	00	2.15	0.14
9	10	5.72	0.15	25	00	2.05	0.14
9	20	5.63	0.15	26	00	1.96	0.13
9	30	5.53	0.15	27	00	1.88	0.13
9	40	5.43	0.15	28	00	1.80	0.13
9	50	5.34	0.15	29	00	1.73	0.13
10	00	5.26	0.15	30	00	1.66	0.13
10	20	5.10	0.15	32	00	1.53	0.13
10	40	4.95	0.14	34	00	1.42	0.12
11	00	4.81	0.14	36	00	1.32	0.12
11	20	4.67	0.14	38	00	1.23	0.12
11	40	4.54	0.14	40	00	1.15	0.11
12	00	4.42	0.14	42	00	1.07	0.11
12	30	4.25	0.14	44	00	1.00	0.11
13	00	4.09	0.14	46	00	0.93	0.10
13	30	3.93	0.14	48	00	0.86	0.10
14	00	3.78	0.14	50	00	0.80	0.09
14	30	3.65	0.14	55	00	0.67	0.08
15	00	3.53	0.14	60	00	0.55	0.07
15	30	3.42	0.14	65	00	0.45	0.06
16	00	3.32	0.14	70	00	0.35	0.05
16	30	3.22	0.14	80	00	0.17	0.03
17	00	3.12	0.14	90	00	0.00	0.00

The refraction values in Table 2 are corrected by multiplying them by the multipliers in Table 2a when the barometric pressure and the temperature differ from those on which Table 2 is based, i. e. 29.6 inches and 50° F.

If the barometric pressure is not known, it may be estimated from the elevation of the locality in accordance with the values given in Table 2a. Otherwise the elevations are disregarded.

TABLE 2a

To correct Table 2. See Examples below.

MULTIPLIERS FOR OBSERVED BAROMETRIC PRESSURE OR ELEVATION

Bar. (Inches)	Elev. (Feet)	Multiplier	Bar. (Inches)	Elev. (Feet)	Multiplier
30.5	−451	1.03	25.4	+4535	0.86
30.2	−181	1.02	25.1	4859	0.85
30.0	00	1.01	24.8	5186	0.84
29.9	+ 91	1.01	24.5	5518	0.83
29.6	366	1.00	24.2	5854	0.82
29.3	643	0.99	23.9	6194	0.81
29.0	924	0.98	23.6	6538	0.80
28.7	1207	0.97	23.3	6887	0.79
28.4	1493	0.96	23.0	7239	0.78
28.1	1783	0.95	22.7	7597	0.77
27.8	2075	0.94	22.4	7960	0.76
27.5	2371	0.93	22.1	8327	0.75
27.2	2670	0.92	21.8	8700	0.74
26.9	2972	0.91	21.5	9077	0.73
26.6	3277	0.90	21.2	9460	0.72
26.3	3586	0.89	20.9	9848	0.71
26.0	3899	0.88	20.6	10242	0.70
25.7	4215	0.87	20.3	10642	0.69
25.4	4535	0.86	20.0	11047	0.68

MULTIPLIERS FOR TEMPERATURE

Temp. Deg. F	Multiplier	Temp. Deg. F	Multiplier	Temp. Deg. F	Multiplier
−20	1.16	+30	1.04	+ 80	0.94
−10	1.13	+40	1.02	+ 90	0.93
0	1.11	+50	1.00	+100	0.91
+10	1.08	+60	0.98	+110	0.90
+20	1.06	+70	0.96	+120	0.88

Example. Sun: Meas. Alt. = 30°; Bar. = 26 in. or Elev. 3900 ft.; Temp. 70° F.
Refraction = 1.66′ (0.88) (0.96) = 1.40′. Parallax = 0.13′.
True Alt. = 30° 00.00′ − 1.40′ + 0.13′ = 29° 58.73′.

Example. Star: Meas. Alt. = 25°; Bar. = 24.5 or Elev. 5518 ft.; Temp. 10° F.
Refraction = 2.05′ (0.83) (1.08) = 1.84′.
True Alt. = 25° 00.00′ − 1.84′ = 24° 58.16′.

TABLE 3

POLAR DISTANCE OF POLARIS, 1963

For 0h Universal Time or Greenwich Time

	Polar Distance			Polar Distance	
	Angle	Cotan		Angle	Cotan
1963	° ′		1963	° ′	
Jan. 1	0 54.26	63.36	July 10	0 54.75	62.79
11	0 54.23	63.38	20	0 54.74	62.79
21	0 54.22	63.40	30	0 54.73	62.81
31	0 54.22	63.40			
Feb. 10	0 54.23	63.39	Aug. 9	0 54.70	62.84
20	0 54.25	63.37	19	0 54.67	62.88
			29	0 54.63	62.92
Mar. 2	0 54.28	63.33	Sept. 8	0 54.59	62.97
12	0 54.31	63.29	18	0 54.54	63.03
22	0 54.36	63.24	28	0 54.48	63.10
Apr. 1	0 54.41	63.18	Oct. 8	0 54.42	63.16
11	0 54.46	63.12	18	0 54.36	63.24
21	0 54.51	63.07	28	0 54.29	63.31
May 1	0 54.56	63.01	Nov. 7	0 54.23	63.39
11	0 54.61	62.95	17	0 54.17	63.46
21	0 54.65	62.90	27	0 54.11	63.53
31	0 54.68	62.86			
			Dec. 7	0 54.06	63.59
June 10	0 54.71	62.83	17	0 54.01	63.64
20	0 54.73	62.80	27	0 53.97	63.69
30	0 54.74	62.79			

Declination = 90° − Polar Distance

TABLE 4

THE SUN'S SEMI-DIAMETER, 1963

For 0h Universal Time or Greenwich Civil Time

Date	Semi-Diam.	Date	Semi-Diam.	Date	Semi-Diam.
Jan. 1	16.29	May 1	15.90	Sept. 8	15.90
11	16.29	11	15.86	18	15.94
21	16.28	21	15.83	28	15.99
31	16.26	31	15.80		
Feb. 10	16.24	June 10	15.78	Oct. 8	16.03
20	16.20	20	15.76	18	16.08
		30	15.76	28	16.12
Mar. 2	16.17	July 10	15.76	Nov. 7	16.16
12	16.12	20	15.76	17	16.20
22	16.08	30	15.78	27	16.23
April 1	16.03	Aug. 9	15.80	Dec. 7	16.26
11	15.99	19	15.83	17	16.28
21	15.94	29	15.86	27	16.29

TABLE 5

Increase in GHA for Elapsed Time.

Min.	0h °	0h ′	1h °	1h ′	2h °	2h ′	3h °	3h ′
0	0	0.0	15	2.5	30	4.9	45	7.4
1	0	15.0	15	17.5	30	19.9	45	22.4
2	0	30.1	15	32.5	30	35.0	45	37.5
3	0	45.1	15	47.6	30	50.1	45	52.5
4	1	0.2	16	2.6	31	5.1	46	7.6
5	1	15.2	16	17.7	31	20.1	46	22.6
6	1	30.2	16	32.7	31	35.2	46	37.6
7	1	45.3	16	47.8	31	50.2	46	52.7
8	2	0.3	17	2.8	32	5.3	47	7.7
9	2	15.4	17	17.8	32	20.3	47	22.8
10	2	30.4	17	32.9	32	35.3	47	37.8
11	2	45.5	17	47.9	32	50.4	47	52.8
12	3	0.5	18	3.0	33	5.4	48	7.9
13	3	15.5	18	18.0	33	20.5	48	22.9
14	3	30.6	18	33.0	33	35.5	48	38.0
15	3	45.6	18	48.1	33	50.5	48	53.0
16	4	0.7	19	3.1	34	5.6	49	8.0
17	4	15.7	19	18.2	34	20.6	49	23.1
18	4	30.7	19	33.2	34	35.7	49	38.1
19	4	45.8	19	48.2	34	50.7	49	53.2
20	5	0.8	20	3.3	35	5.7	50	8.2
21	5	15.9	20	18.3	35	20.8	50	23.3
22	5	30.9	20	33.4	35	35.8	50	38.3
23	5	45.9	20	48.4	35	50.9	50	53.3
24	6	1.0	21	3.4	36	5.9	51	8.4
25	6	16.0	21	18.5	36	21.0	51	23.4
26	6	31.1	21	33.5	36	36.0	51	38.5
27	6	46.1	21	48.6	36	51.0	51	53.5
28	7	1.1	22	3.6	37	6.1	52	8.5
29	7	16.2	22	18.7	37	21.1	52	23.6
30	7	31.2	22	33.7	37	36.2	52	38.6
31	7	46.3	22	48.7	37	51.2	52	53.7
32	8	1.3	23	3.8	38	6.2	53	8.7
33	8	16.4	23	18.8	38	21.3	53	23.7
34	8	31.4	23	33.9	38	36.3	53	38.8
35	8	46.4	23	48.9	38	51.4	53	53.8
36	9	1.5	24	3.9	39	6.4	54	8.9
37	9	16.5	24	19.0	39	21.4	54	23.9
38	9	31.6	24	34.0	39	36.5	54	39.0
39	9	46.6	24	49.1	39	51.5	54	54.0
40	10	1.6	25	4.1	40	6.6	55	9.0
41	10	16.7	25	19.1	40	21.6	55	24.1
42	10	31.7	25	34.2	40	36.7	55	39.1
43	10	46.8	25	49.2	40	51.7	55	54.2
44	11	1.8	26	4.3	41	6.7	56	9.2
45	11	16.8	26	19.3	41	21.8	56	24.2
46	11	31.9	26	34.4	41	36.8	56	39.3
47	11	46.9	26	49.4	41	51.9	56	54.3
48	12	2.0	27	4.4	42	6.9	57	9.4
49	12	17.0	27	19.5	42	21.9	57	24.4
50	12	32.1	27	34.5	42	37.0	57	39.4
51	12	47.1	27	49.6	42	52.0	57	54.5
52	13	2.1	28	4.6	43	7.1	58	9.5
53	13	17.2	28	19.6	43	22.1	58	24.6
54	13	32.2	28	34.7	43	37.1	58	39.6
55	13	47.3	28	49.7	43	52.2	58	54.6
56	14	2.3	29	4.8	44	7.2	59	9.7
57	14	17,3	29	19.8	44	22.3	59	24.7
58	14	32.4	29	34.8	44	37.3	59	39.8
59	14	47.4	29	49.9	44	52.4	59	54.8
60	15	2.5	30	4.9	45	7.4	60	9.9

(Column heading: Hours of Greenwich Civil Time)

Sec.	Corr. ′
0	0.0
1	0.3
2	0.5
3	0.8
4	1.0
5	1.3
6	1.5
7	1.8
8	2.0
9	2.3
10	2.5
11	2.8
12	3.0
13	3.3
14	3.5
15	3.8
16	4.0
17	4.3
18	4.5
19	4.8
20	5.0
21	5,3
22	5.5
23	5.8
24	6.0
25	6.3
26	6.5
27	6.8
28	7.0
29	7.3
30	7.5
31	7.8
32	8.0
33	8.3
34	8.5
35	8.8
36	9.0
37	9.3
38	9.5
39	9.8
40	10.0
41	10.3
42	10.5
43	10.8
44	11.0
45	11.3
46	11.5
47	11.8
48	12.0
49	12.3
50	12.5
51	12.8
52	13.0
53	13.3
54	13.5
55	13.8
56	14.0
57	14.3
58	14.5
59	14.8
60	15.0

TABLE 5—(Continued)
Increase in GHA for Elapsed Time.

Min.	Hours of Greenwich Civil Time											
	4h		5h		6h		7h		8h		9h	
	°	′	°	′	°	′	°	′	°	′	°	′
0	60	9.9	75	12.3	90	14.8	105	17.2	120	19.7	135	22.2
1	60	24.9	75	27.4	90	29.8	105	32.3	120	34.8	135	37.2
2	60	39.9	75	42.4	90	44.9	105	47.3	120	49.8	135	52.3
3	60	55.0	75	57.4	90	59.9	106	2.4	121	4.8	136	7.3
4	61	10.0	76	12.5	91	14.9	106	17.4	121	19.9	136	22.3
5	61	25.1	76	27.5	91	30.0	106	32.5	121	34.9	136	37.4
6	61	40.1	76	42.6	91	45.0	106	47.5	121	50.0	136	52.4
7	61	55.1	76	57.6	92	0.1	107	2.5	122	5.0	137	7.5
8	62	10.2	77	12.6	92	15.1	107	17.6	122	20.0	137	22.5
9	62	25.2	77	27.7	92	30.2	107	32.6	122	35.1	137	37.5
10	62	40.3	77	42.7	92	45.2	107	47.7	122	50.1	137	52.6
11	62	55.3	77	57.8	93	0.2	108	2.7	123	5.2	138	7.6
12	63	10.3	78	12.8	93	15.3	108	17.7	123	20.2	138	22.7
13	63	25.4	78	27.9	93	30.3	108	32.8	123	35.2	138	37.7
14	63	40.4	78	42.9	93	45.4	108	47.8	123	50.3	138	52.8
15	63	55.5	78	57.9	94	0.4	109	2.9	124	5.3	139	7.8
16	64	10.5	79	13.0	94	15.4	109	17.9	124	20.4	139	22.8
17	64	25.6	79	28.0	94	30.5	109	32.9	124	35.4	139	37.9
18	64	40.6	79	43.1	94	45.5	109	48.0	124	50.4	139	52.9
19	64	55.6	79	58.1	95	0.6	110	3.0	125	5.5	140	8.0
20	65	10.7	80	13.1	95	15.6	110	18.1	125	20.5	140	23.0
21	65	25.7	80	28.2	95	30.6	110	33.1	125	35.6	140	38.0
22	65	40.8	80	43.2	95	45.7	110	48.2	125	50.6	140	53.1
23	65	55.8	80	58.3	96	0.7	111	3.2	126	5.7	141	8.1
24	66	10.8	81	13.3	96	15.8	111	18.2	126	20.7	141	23.2
25	66	25.9	81	28.3	96	30.8	111	33.3	126	35.7	141	38.2
26	66	40.9	81	43.4	96	45.8	111	48.3	126	50.8	141	53.2
27	66	56.0	81	58.4	97	0.9	112	3.4	127	5.8	142	8.3
28	67	11.0	82	13.5	97	15.9	112	18.4	127	20.9	142	23.3
29	67	26.0	82	28.5	97	31.0	112	33.4	127	35.9	142	38.4
30	67	41.1	82	43.6	97	46.0	112	48.5	127	50.9	142	53.4
31	67	56.1	82	58.6	98	1.1	113	3.5	128	6.0	143	8.4
32	68	11.2	83	13.6	98	16.1	113	18.6	128	21.0	143	23.5
33	68	26.2	83	28.7	98	31.1	113	33.6	128	36.1	143	38.5
34	68	41.2	83	43.7	98	46.2	113	48.6	128	51.1	143	53.6
35	68	56.3	83	58.8	99	1.2	114	3.7	129	6.1	144	8.6
36	69	11.3	84	13.8	99	16.3	114	18.7	129	21.2	144	23.7
37	69	26.4	84	28.8	99	31.3	114	33.8	129	36.2	144	38.7
38	69	41.4	84	43.9	99	46.3	114	48.8	129	51.3	144	53.7
39	69	56.5	84	58.9	100	1.4	115	3.9	130	6.3	145	8.8
40	70	11.5	85	14.0	100	16.4	115	18.9	130	21.4	145	23.8
41	70	26.5	85	29.0	100	31.5	115	33.9	130	36.4	145	38.9
42	70	41.6	85	44.0	100	46.5	115	49.0	130	51.4	145	53.9
43	70	56.6	85	59.1	101	1.5	116	4.0	131	6.5	146	8.9
44	71	11.7	86	14.1	101	16.6	116	19.1	131	21.5	146	24.0
45	71	26.7	86	29.2	101	31.6	116	34.1	131	36.6	146	39.0
46	71	41.7	86	44.2	101	46.7	116	49.1	131	51.6	146	54.1
47	71	56.8	86	59.2	102	1.7	117	4.2	132	6.6	147	9.1
48	72	11.8	87	14.3	102	16.8	117	19.2	132	21.7	147	24.1
49	72	26.9	87	29.3	102	31.8	117	34.3	132	36.7	147	39.2
50	72	41.9	87	44.4	102	46.8	117	49.3	132	51.8	147	54.2
51	72	56.9	87	59.4	103	1.9	118	4.3	133	6.8	148	9.3
52	73	12.0	88	14.5	103	16.9	118	19.4	133	21.8	148	24.3
53	73	27.0	88	29.5	103	32.0	118	34.4	133	36.9	148	39.3
54	73	42.1	88	44.5	103	47.0	118	49.5	133	51.9	148	54.4
55	73	57.1	88	59.6	104	2.0	119	4.5	134	7.0	149	9.4
56	74	12.2	89	14.6	104	17.1	119	19.5	134	22.0	149	24.5
57	74	27.2	89	29.7	104	32.1	119	34.6	134	37.0	149	39.5
58	74	42.2	89	44.7	104	47.2	119	49.6	134	52.1	149	54.6
59	74	57.3	89	59.7	105	2.2	120	4.7	135	7.1	150	9.6
60	75	12.3	90	14.8	105	17.2	120	19.7	135	22.2	150	24.6

TABLE 5 —(Continued)

Increase in GHA for Elapsed Time.

Min.	10h °	10h ′	11h °	11h ′	12h °	12h ′	13h °	13h ′
0	150	24.6	165	27.1	180	29.6	195	32.0
1	150	39.7	165	42.1	180	44.6	195	47.1
2	150	54.7	165	57.2	180	59.7	196	2.1
3	151	9.8	166	12.2	181	14.7	196	17.2
4	151	24.8	166	27.3	181	29.7	196	32.2
5	151	39.8	166	42.3	181	44.8	196	47.2
6	151	54.9	166	57.3	181	59.8	197	2.3
7	152	9.9	167	12.4	182	14.9	197	17.3
8	152	25.0	167	27.4	182	29.9	197	32.4
9	152	40.0	167	42.5	182	44.9	197	47.4
10	152	55.1	167	57.5	183	0.0	198	2.4
11	153	10.1	168	12.6	183	15.0	198	17.5
12	153	25.1	168	27.6	183	30.1	198	32.5
13	153	40.2	168	42.6	183	45.1	198	47.6
14	153	55.2	168	57.7	184	0.1	199	2.6
15	154	10.3	169	12.7	184	15.2	199	17.6
16	154	25.3	169	27.8	184	30.2	199	32.7
17	154	40.3	169	42.8	184	45.3	199	47.7
18	154	55.4	169	57.8	185	0.3	200	2.8
19	155	10.4	170	12.9	185	15.3	200	17.8
20	155	25.5	170	27.9	185	30.4	200	32.9
21	155	40.5	170	43.0	185	45.4	200	47.9
22	155	55.5	170	58.0	186	0.5	201	2.9
23	156	10.6	171	13.0	186	15.5	201	18.0
24	156	25.6	171	28.1	186	30.6	201	33.0
25	156	40.7	171	43.1	186	45.6	201	48.1
26	156	55.7	171	58.2	187	0.6	202	3.1
27	157	10.7	172	13.2	187	15.7	202	18.1
28	157	25.8	172	28.2	187	30.7	202	33.2
29	157	40.8	172	43.3	187	45.8	202	48.2
30	157	55.9	172	58.3	188	0.8	203	3.3
31	158	10.9	173	13.4	188	15.8	203	18.3
32	158	26.0	173	28.4	188	30.9	203	33.3
33	158	41.0	173	43.5	188	45.9	203	48.4
34	158	56.0	173	58.5	189	1.0	204	3.4
35	159	11.1	174	13.5	189	16.0	204	18.5
36	159	26.1	174	28.6	189	31.0	204	33.5
37	159	41.2	174	43.6	189	46.1	204	48.6
38	159	56.2	174	58.7	190	1.1	205	3.6
39	160	11.2	175	13.7	190	16.2	205	18.6
40	160	26.3	175	28.7	190	31.2	205	33.7
41	160	41.3	175	43.8	190	46.2	205	48.7
42	160	56.4	175	58.8	191	1.3	206	3.8
43	161	11.4	176	13.9	191	16.3	206	18.8
44	161	26.4	176	28.9	191	31.4	206	33.8
45	161	41.5	176	43.9	191	46.4	206	48.9
46	161	56.5	176	59.0	192	1.5	207	3.9
47	162	11.6	177	14.0	192	16.5	207	19.0
48	162	26.6	177	29.1	192	31.5	207	34.0
49	162	41.6	177	44.1	192	46.6	207	49.0
50	162	56.7	177	59.2	193	1.6	208	4.1
51	163	11.7	178	14.2	193	16.7	208	19.1
52	163	26.8	178	29.2	193	31.7	208	34.2
53	163	41.8	178	44.3	193	46.7	208	49.2
54	163	56.9	178	59.3	194	1.8	209	4.2
55	164	11.9	179	14.4	194	16.8	209	19.3
56	164	26.9	179	29.4	194	31.9	209	34.3
57	164	42.0	179	44.4	194	46.9	209	49.4
58	164	57.0	179	59.5	195	1.9	210	4.4
59	165	12.1	180	14.5	195	17.0	210	19.5
60	165	27.1	180	29.6	195	32.0	210	34.5

Sec.	Corr. ′
0	0.0
1	0.3
2	0.5
3	0.8
4	1.0
5	1.3
6	1.5
7	1.8
8	2.0
9	2.3
10	2.5
11	2.8
12	3.0
13	3.3
14	3.5
15	3.8
16	4.0
17	4.3
18	4.5
19	4.8
20	5.0
21	5.3
22	5.5
23	5.8
24	6.0
25	6.3
26	6.5
27	6.8
28	7.0
29	7.3
30	7.5
31	7.8
32	8.0
33	8.3
34	8.5
35	8.8
36	9.0
37	9.3
38	9.5
39	9.8
40	10.0
41	10.3
42	10.5
43	10.8
44	11.0
45	11.3
46	11.5
47	11.8
48	12.0
49	12.3
50	12.5
51	12.8
52	13.0
53	13.3
54	13.5
55	13.8
56	14.0
57	14.3
58	14.5
59	14.8
60	15.0

TABLE 5—(Continued)

Increase in GHA for Elapsed Time

Min.	Hours of Greenwich Civil Time											
	14^h		15^h		16^h		17^h		18^h		19^h	
	°	′	°	′	°	′	°	′	°	′	°	′
0	210	34.5	225	37.0	240	39.4	255	41.9	270	44.4	285	46.8
1	210	49.5	225	52.0	240	54.5	255	56.9	270	59.4	286	1.9
2	211	4.6	226	7.0	241	9.5	256	12.0	271	14.4	286	16.9
3	211	19.6	226	22.1	241	24.5	256	27.0	271	29.5	286	31.9
4	211	34.7	226	37.1	241	39.6	256	42.1	271	44.5	286	47.0
5	211	49.7	226	52.2	241	54.6	256	57.1	271	59.6	287	2.0
6	212	4.7	227	7.2	242	9.7	257	12.1	272	14.6	287	17.1
7	212	19.8	227	22.2	242	24.7	257	27.2	272	29.6	287	32.1
8	212	34.8	227	37.3	242	39.8	257	42.2	272	44.7	287	47.1
9	212	49.9	227	52.3	242	54.8	257	57.3	272	59.7	288	2.2
10	213	4.9	228	7.4	243	9.8	258	12.3	273	14.8	288	17.2
11	213	19.9	228	22.4	243	24.9	258	27.3	273	29.8	288	32.3
12	213	35.0	228	37.5	243	39.9	258	42.4	273	44.8	288	47.3
13	213	50.0	228	52.5	243	55.0	258	57.4	273	59.9	289	2.4
14	214	5.1	229	7.5	244	10.0	259	12.5	274	14.9	289	17.4
15	214	20.1	229	22.6	244	25.0	259	27.5	274	30.0	289	32.4
16	214	35.2	229	37.6	244	40.1	259	42.5	274	45.0	289	47.5
17	214	50.2	229	52.7	244	55.1	259	57.6	275	0.0	290	2.5
18	215	5.2	230	7.7	245	10.2	260	12.6	275	15.1	290	17.6
19	215	20.3	230	22.7	245	25.2	260	27.7	275	30.1	290	32.6
20	215	35.3	230	37.8	245	40.2	260	42.7	275	45.2	290	47.6
21	215	50.4	230	52.8	245	55.3	260	57.8	276	0.2	291	2.7
22	216	5.4	231	7.9	246	10.3	261	12.8	276	15.3	291	17.7
23	216	20.4	231	22.9	246	25.4	261	27.8	276	30.3	291	32.8
24	216	35.5	231	37.9	246	40.4	261	42.9	276	45.3	291	47.8
25	216	50.5	231	53.0	246	55.4	261	57.9	277	0.4	292	2.8
26	217	5.6	232	8.0	247	10.5	262	13.0	277	15.4	292	17.9
27	217	20.6	232	23.1	247	25.5	262	28.0	277	30.5	292	32.9
28	217	35.6	232	38.1	247	40.6	262	43.0	277	45.5	292	48.0
29	217	50.7	232	53.2	247	55.6	262	58.1	278	0.5	293	3.0
30	218	5.7	233	8.2	248	10.7	263	13.1	278	15.6	293	18.0
31	218	20.8	233	23.2	248	25.7	263	28.2	278	30.6	293	33.1
32	218	35.8	233	38.3	248	40.7	263	43.2	278	45.7	293	48.1
33	218	50.8	233	53.3	248	55.8	263	58.2	279	0.7	294	3.2
34	219	5.9	234	8.4	249	10.8	264	13.3	279	15.7	294	18.2
35	219	20.9	234	23.4	249	25.9	264	28.3	279	30.8	294	33.3
36	219	36.0	234	38.4	249	40.9	264	43.4	279	45.8	294	48.3
37	219	51.0	234	53.5	249	55.9	264	58.4	280	0.9	295	3.3
38	220	6.1	235	8.5	250	11.0	265	13.4	280	15.9	295	18.4
39	220	21.1	235	23.6	250	26.0	265	28.5	280	31.0	295	33.4
40	220	36.1	235	38.6	250	41.1	265	43.5	280	46.0	295	48.5
41	220	51.2	235	53.6	250	56.1	265	58.6	281	1.0	296	3.5
42	221	6.2	236	8.7	251	11.1	266	13.6	281	16.1	296	18.5
43	221	21.3	236	23.7	251	26.2	266	28.7	281	31.1	296	33.6
44	221	36.3	236	38.8	251	41.2	266	43.7	281	46.2	296	48.6
45	221	51.3	236	53.8	251	56.3	266	58.7	282	1.2	297	3.7
46	222	6.4	237	8.8	252	11.3	267	13.8	282	16.2	297	18.7
47	222	21.4	237	23.9	252	26.4	267	28.8	282	31.3	297	33.7
48	222	36.5	237	38.9	252	41.4	267	43.9	282	46.3	297	48.8
49	222	51.5	237	54.0	252	56.4	267	58.9	283	1.4	298	3.8
50	223	6.5	238	9.0	253	11.5	268	13.9	283	16.4	298	18.9
51	223	21.6	238	24.1	253	26.5	268	29.0	283	31.4	298	33.9
52	223	36.6	238	39.1	253	41.6	268	44.0	283	46.5	298	48.9
53	223	51.7	238	54.1	253	56.6	268	59.1	284	1.5	299	4.0
54	224	6.7	239	9.2	254	11.6	269	14.1	284	16.6	299	19.0
55	224	21.8	239	24.2	254	26.7	269	29.1	284	31.6	299	34.1
56	224	36.8	239	39.3	254	41.7	269	44.2	284	46.6	299	49.1
57	224	51.8	239	54.3	254	56.8	269	59.2	285	1.7	300	4.2
58	225	6.9	240	9.3	255	11.8	270	14.3	285	16.7	300	19.2
59	225	21.9	240	24.4	255	26.8	270	29.3	285	31.8	300	34.2
60	225	37.0	240	39.4	255	41.9	270	44.4	285	46.8	300	49.3

TABLE 5—(Continued)

Increase in GHA for Elapsed Time

Min.	Hours of Greenwich Civil Time							
	20h		21h		22h		23h	
	°	′	°	′	°	′	°	′
0	300	49.3	315	51.7	330	54.2	345	56.7
1	301	4.3	316	6.8	331	9.3	346	11.7
2	301	19.4	316	21.8	331	24.3	346	26.8
3	301	34.4	316	36.9	331	39.3	346	41.8
4	301	49.4	316	51.9	331	54.4	346	56.8
5	302	4.5	317	7.0	332	9.4	347	11.9
6	302	19.5	317	22.0	332	24.5	347	26.9
7	302	34.6	317	37.0	332	39.5	347	42.0
8	302	49.6	317	52.1	332	54.5	347	57.0
9	303	4.7	318	7.1	333	9.6	348	12.0
10	303	19.7	318	22.2	333	24.6	348	27.1
11	303	34.7	318	37.2	333	39.7	348	42.1
12	303	49.8	318	52.2	333	54.7	348	57.2
13	304	4.8	319	7.3	334	9.7	349	12.2
14	304	19.9	319	22.3	334	24.8	349	27.2
15	304	34.9	319	37.4	334	39.8	349	42.3
16	304	49.9	319	52.4	334	54.9	349	57.3
17	305	5.0	320	7.4	335	9.9	350	12.4
18	305	20.0	320	22.5	335	24.9	350	27.4
19	305	35.1	320	37.5	335	40.0	350	42.5
20	305	50.1	320	52.6	335	55.0	350	57.5
21	306	5.1	321	7.6	336	10.1	351	12.5
22	306	20.2	321	22.6	336	25.1	351	27.6
23	306	35.2	321	37.7	336	40.2	351	42.6
24	306	50.3	321	52.7	336	55.2	351	57.7
25	307	5.3	322	7.8	337	10.2	352	12.7
26	307	20.3	322	22.8	337	25.3	352	27.7
27	307	35.4	322	37.9	337	40.3	352	42.8
28	307	50.4	322	52.9	337	55.4	352	57.8
29	308	5.5	323	7.9	338	10.4	353	12.9
30	308	20.5	323	23.0	338	25.4	353	27.9
31	308	35.6	323	38.0	338	40.5	353	42.9
32	308	50.6	323	53.1	338	55.5	353	58.0
33	309	5.6	324	8.1	339	10.6	354	13.0
34	309	20.7	324	23.1	339	25.6	354	28.1
35	309	35.7	324	38.2	339	40.6	354	43.1
36	309	50.8	324	53.2	339	55.7	354	58.2
37	310	5.8	325	8.3	340	10.7	355	13.2
38	310	20.8	325	23.3	340	25.8	355	28.2
39	310	35.9	325	38.3	340	40.8	355	43.3
40	310	50.9	325	53.4	340	55.8	355	58.3
41	311	6.0	326	8.4	341	10.9	356	13.4
42	311	21.0	326	23.5	341	25.9	356	28.4
43	311	36.0	326	38.5	341	41.0	356	43.4
44	311	51.1	326	53.6	341	56.0	356	58.5
45	312	6.1	327	8.6	342	11.1	357	13.5
46	312	21.2	327	23.6	342	26.1	357	28.6
47	312	36.2	327	38.7	342	41.1	357	43.6
48	312	51.3	327	53.7	342	56.2	357	58.6
49	313	6.3	328	8.8	343	11.2	358	13.7
50	313	21.3	328	23.8	343	26.3	358	28.7
51	313	36.4	328	38.8	343	41.3	358	43.8
52	313	51.4	328	53.9	343	56.3	358	58.8
53	314	6.5	329	8.9	344	11.4	359	13.8
54	314	21.5	329	24.0	344	26.4	359	28.9
55	314	36.5	329	39.0	344	41.5	359	43.9
56	314	51.6	329	54.0	344	56.5	359	59.0
57	315	6.6	330	9.1	345	11.5	0	14.0
58	315	21.7	330	24.1	345	26.6	0	29.1
59	315	36.7	330	39.2	345	41.6	0	44.1
60	315	51.7	330	54.2	345	56.7	0	59.1

Sec.	Corr.
	′
0	0.0
1	0.3
2	0.5
3	0.8
4	1.0
5	1.3
6	1.5
7	1.8
8	2.0
9	2.3
10	2.5
11	2.8
12	3.0
13	3.3
14	3.5
15	3.8
16	4.0
17	4.3
18	4.5
19	4.8
20	5.0
21	5.3
22	5.5
23	5.8
24	6.0
25	6.3
26	6.5
27	6.8
28	7.0
29	7.3
30	7.5
31	7.8
32	8.0
33	8.3
34	8.5
35	8.8
36	9.0
37	9.3
38	9.5
39	9.8
40	10.0
41	10.3
42	10.5
43	10.8
44	11.0
45	11.3
46	11.5
47	11.8
48	12.0
49	12.3
50	12.5
51	12.8
52	13.0
53	13.3
54	13.5
55	13.8
56	14.0
57	14.3
58	14.5
59	14.8
60	15.0

TABLE 6
CORRECTIONS TO BE APPLIED TO LATITUDE TO OBTAIN THE TRUE ALTITUDE OF POLARIS, 1963

t	Corr.	t	Corr.	t	Corr.	t	Corr.
°	′	°	′	°	′	°	′
0	+54.3	45	+38.2	90	− 0.4	135	−38.6
1	54.3	46	37.5	91	1.4	136	39.3
2	54.3	47	36.8	92	2.3	137	39.9
3	54.2	48	36.1	93	3.3	138	40.6
4	54.2	49	35.4	94	4.2	139	41.2
5	+54.1	50	+34.7	95	− 5.2	140	−41.8
6	54.0	51	33.9	96	6.1	141	42.4
7	53.9	52	33.2	97	7.0	142	43.0
8	53.8	53	32.4	98	8.0	143	43.5
9	53.6	54	31.6	99	8.9	144	44.1
10	+53.5	55	+30.9	100	− 9.8	145	−44.6
11	53.3	56	30.1	101	10.8	146	45.2
12	53.1	57	29.3	102	11.7	147	45.7
13	52.9	58	28.5	103	12.6	148	46.2
14	52.7	59	27.7	104	13.5	149	46.7
15	+52.4	60	+26.8	105	−14.5	150	−47.2
16	52.2	61	26.0	106	15.4	151	47.6
17	51.9	62	25.2	107	16.3	152	48.1
18	51.6	63	24.3	108	17.2	153	48.5
19	51.3	64	23.5	109	18.1	154	48.9
20	+51.0	65	+22.6	110	−19.0	155	−49.3
21	50.7	66	21.7	111	19.8	156	49.7
22	50.3	67	20.9	112	20.7	157	50.1
23	49.9	68	20.0	113	21.6	158	50.4
24	49.6	69	19.1	114	22.4	159	50.8
25	+49.2	70	+18.2	115	−23.3	160	−51.1
26	48.8	71	17.3	116	24.2	161	51.4
27	48.3	72	16.4	117	25.0	162	51.7
28	47.9	73	15.5	118	25.8	163	52.0
29	47.4	74	14.6	119	26.7	164	52.3
30	+46.9	75	+13.7	120	−27.5	165	−52.5
31	46.4	76	12.7	121	28.3	166	52.7
32	46.0	77	11.8	122	29.1	167	53.0
33	45.4	78	10.9	123	29.9	168	53.2
34	44.9	79	10.0	124	30.7	169	53.4
35	+44.4	80	+ 9.0	125	−31.4	170	−53.5
36	43.8	81	8.1	126	32.2	171	53.7
37	43.2	82	7.1	127	33.0	172	53.8
38	42.6	83	6.2	128	33.7	173	53.9
39	42.0	84	5.2	129	34.4	174	54.0
40	+41.4	85	+ 4.3	130	−35.2	175	−54.1
41	40.8	86	3.4	131	35.9	176	54.2
42	40.2	87	2.4	132	36.6	177	54.3
43	39.5	88	1.5	133	37.3	178	54.3
44	38.9	89	+ 0.5	134	38.0	179	54.3
45	38.2	90	− 0.4	135	38.6	180	54.3

TABLE 7

BEARING OF POLARIS AT ELONGATION
1963

Polar Dist.	0° 54.10′	0° 54.30′	0° 54.50′	0° 54.70′	Polar Dist.	0° 54.10′	0° 54.30′	0° 54.50′	0° 54.70′
Lat.	Bearing at Elongation				Lat.	Bearing at Elongation			
°	° ′	° ′	° ′	° ′	°	° ′	° ′	° ′	° ′
10	0 54.9	0 55.1	0 55.3	0 55.5	40	1 10.6	1 10.9	1 11.1	1 11.4
11	0 55.1	0 55.3	0 55.5	0 55.7	41	1 11.7	1 12.0	1 12.2	1 12.5
12	0 55.3	0 55.5	0 55.7	0 55.9	42	1 12.8	1 13.1	1 13.3	1 13.6
13	0 55.5	0 55.7	0 55.9	0 56.1	43	1 14.0	1 14.2	1 14.5	1 14.8
14	0 55.8	0 56.0	0 56.2	0 56.4	44	1 15.2	1 15.5	1 15.8	1 16.0
15	0 56.0	0 56.2	0 56.4	0 56.6	45	1 16.5	1 16.8	1 17.1	1 17.4
16	0 56.3	0 56.5	0 56.7	0 56.9	46	1 17.9	1 18.2	1 18.5	1 18.7
17	0 56.6	0 56.8	0 57.0	0 57.2	47	1 19.3	1 19.6	1 19.9	1 20.2
18	0 56.9	0 57.1	0 57.3	0 57.5	48	1 20.9	1 21.2	1 21.5	1 21.8
19	0 57.2	0 57.4	0 57.6	0 57.9	49	1 22.5	1 22.8	1 23.1	1 23.4
20	0 57.6	0 57.8	0 58.0	0 58.2	50	1 24.2	1 24.5	1 24.8	1 25.1
21	0 57.9	0 58.2	0 58.4	0 58.6	51	1 26.0	1 26.3	1 26.6	1 26.9
22	0 58.3	0 58.6	0 58.8	0 59.0	52	1 27.9	1 28.2	1 28.5	1 28.9
23	0 58.8	0 59.0	0 59.2	0 59.4	53	1 29.9	1 30.2	1 30.6	1 30.9
24	0 59.2	0 59.4	0 59.7	0 59.9	54	1 32.0	1 32.4	1 32.7	1 33.1
25	0 59.7	0 59.9	1 00.1	1 00.4	55	1 34.3	1 34.7	1 35.0	1 35.4
26	1 00.2	1 00.4	1 00.6	1 00.9	56	1 36.8	1 37.1	1 37.5	1 37.8
27	1 00.7	1 00.9	1 01.2	1 01.4	57	1 39.3	1 39.7	1 40.1	1 40.4
28	1 01.3	1 01.5	1 01.7	1 02.0	58	1 42.1	1 42.5	1 42.9	1 43.2
29	1 01.9	1 02.1	1 02.3	1 02.5	59	1 45.1	1 45.4	1 45.8	1 46.2
30	1 02.5	1 02.7	1 02.9	1 03.2	60	1 48.2	1 48.6	1 49.0	1 49.4
31	1 03.1	1 03.3	1 03.6	1 03.8	61	1 51.6	1 52.0	1 52.4	1 52.8
32	1 03.8	1 04.0	1 04.3	1 04.5	62	1 55.3	1 55.7	1 56.1	1 56.5
33	1 04.5	1 04.7	1 05.0	1 05.2	63	1 59.2	1 59.6	2 00.1	2 00.5
34	1 05.3	1 05.5	1 05.7	1 06.0	64	2 03.4	2 03.9	2 04.3	2 04.8
35	1 06.0	1 06.3	1 06.5	1 06.8	65	2 08.0	2 08.5	2 09.0	2 09.5
36	1 06.9	1 07.1	1 07.4	1 07.6	66	2 13.0	2 13.5	2 14.0	2 14.5
37	1 07.7	1 08.0	1 08.2	1 08.5	67	2 18.5	2 19.0	2 19.5	2 20.0
38	1 08.7	1 08.9	1 09.2	1 09.4	68	2 24.5	2 25.0	2 25.5	2 26.1
39	1 09.6	1 09.9	1 10.1	1 10.4	69	2 31.0	2 31.6	2 32.1	2 32.7
40	1 10.6	1 10.9	1 11.1	1 11.4	70	2 38.2	2 38.8	2 39.4	2 40.0

To obtain the Bearing at any other declination compute:

$$\text{Bear. Polaris (in minutes)} = \frac{\text{Polar Dist. (in minutes)}}{\cos \text{Lat.}}$$

TABLE 8

POLARIS FOR THE MERIDIAN OF GREENWICH
LATITUDE 40° N, 1963
Universal Time or Greenwich Civil Time

Date	Upper Culmination h	m	Previous East Elongation h	m	Next West Elongation h	m	Next Lower Culmination h	m	Var. Per Day m
1963									
Jan. 1	19	15.6	13	19.7	1	11.5	7	13.6	3.95
11	18	36.1	12	40.2	0	32.0	6	34.1	3.96
21	17	56.5	12	00.6	23	52.4	5	54.5	3.95
31	17	17.0	11	21.1	23	12.9	5	15.0	3.96
Feb. 10	16	37.4	10	41.5	22	33.3	4	35.4	3.95
20	15	57.9	10	02.0	21	53.8	3	55.9	3.95
Mar. 2	15	18.4	9	22.5	21	14.3	3	16.4	3.95
12	14	38.9	8	43.0	20	34.8	2	36.9	3.94
22	13	59.5	8	03.6	19	55.4	1	57.5	3.94
Apr. 1	13	20.1	7	24.2	19	16.0	1	18.1	3.94
11	12	40.7	6	44.8	18	36.6	0	38.7	3.93
21	12	01.4	6	05.5	17	57.3	23	59.4	3.93
May 1	11	22.1	5	26.2	17	18.0	23	20.1	3.92
11	10	42.9	4	47.0	16	38.8	22	40.9	3.92
21	10	03.7	4	07.8	15	59.6	22	01.7	3.92
31	9	24.5	3	28.6	15	20.4	21	22.5	3.91
June 10	8	45.4	2	49.5	14	41.3	20	43.4	3.92
20	8	06.2	2	10.3	14	02.1	20	04.2	3.91
30	7	27.1	1	31.2	13	23.0	19	25.1	3.91
July 10	6	48.0	0	52.1	12	43.9	18	46.0	3.90
20	6	09.0	0	13.1	12	04.9	18	07.0	3.91
30	5	29.9	23	34.0	11	25.8	17	27.9	3.91
Aug. 9	4	50.8	22	54.9	10	46.7	16	48.8	3.91
19	4	11.7	22	15.8	10	07.6	16	09.7	3.92
29	3	32.5	21	36.6	9	28.4	15	30.5	3.91
Sept. 8	2	53.4	20	57.5	8	49.3	14	51.4	3.92
18	2	14.2	20	18.3	8	10.1	14	12.2	3.92
28	1	35.0	19	39.1	7	30.9	13	33.0	3.92
Oct. 8	0	55.8	18	59.9	6	51.7	12	53.8	3.92
18	0	16.6	18	20.7	6	12.5	12	14.6	3.93
27	23	37.3	17	41.4	5	33.2	11	35.3	3.93
Nov. 6	22	58.0	17	02.1	4	53.9	10	56.0	3.94
16	22	18.6	16	22.7	4	14.5	10	16.6	3.94
26	21	39.2	15	43.3	3	35.1	9	37.2	3.94
Dec. 6	20	59.8	15	03.9	2	55.7	8	57.8	3.95
16	20	20.3	14	24.4	2	16.2	8	18.3	3.95
26	19	40.8	13	44.9	1	36.7	7	38.8	3.95
1964									
Jan. 5	19	01.3	13	05.4	0	57.2	6	59.3	

From July 30 to Oct. 18 the East Elongation is for the previous day.
From Jan. 1 to Jan. 11 and from Oct. 27 to Jan. 5 the West Elongation is for the next day.
From Jan. 1 to Apr. 11 and from Oct. 27 to Jan. 5 the lower culmination is for the next day.

TABLE 9

CORRECTIONS TO TIMES OF ELONGATION
FOR DIFFERENT LATITUDES, 1963

Latitude	10°	15°	20°	25°	30°	35°	40°	45°	50°
	m	m	m	m	m	m	m	m	m
West Elongation	+2.4	+2.1	+1.7	+1.4	+1.0	+0.5	0.0	−0.6	−1.3
East Elongation	−2.4	−2.1	−1.7	−1.4	−1.0	−0.5	0.0	+0.6	+1.3

To obtain the precise Local Civil Time (*LCT*) of elongation or culmination at the meridian where the observation is to be made (the local meridian), add .011 m. for each degree east of Greenwich. Subtract if west.

To convert *LCT* to Standard Time, add 4 m. for each degree that the local meridian is west of the Standard Time Meridian. Subtract if east.

Example 1. Find Eastern Standard Time (75th mer. time) of upper culmination May 11, 1963 at 78° W. Long.

GCT of U. C. at G. (Table 8)		$10^h\ 42.9^m$
$.011 \times 78 = .86$	$-$	0.9
LCT of U. C. at 78° W		$10^h\ 42.0^m$
$4 \times 3 = 12$	$+$	12.0
EST of U. C. at 78° W		$10^h\ 54.0^m$

Example 2. Find Pacific Time (120th mer. time) of upper culmination June 18, 1963 at 122° W. Long.

From Table 8, U. C. at G., 1963

June 10 *GCT*		$8^h\ 45.4^m$
Var. per day $= 3.92^m$		
June 10 to June 18 = 8 days		
$8 \times 3.92^m = 31.3^m$	$-$	31.4^m
June 18 *GCT*		$8^h\ 14.0^m$
$.011^m \times 122 = 1.34^m$	$-$	1.3^m
LCT at 122° W		$8^h\ 12.7^m$
$4^m \times 2 = 8^m$	$+$	8.0^m
PST of U. C. at 122° W		$8^h\ 20.7^m$

In order to make ordinary latitude observations, it is sufficient to know the time of culmination of Polaris with an accuracy of five minutes.

TABLE 10

BEARING OF POLARIS AT ALL LOCAL HOUR ANGLES

1963 computed for a polar distance of 0° 54.33′
For Local Hour Angles 0° to 180° the Star is West of North
and from 180° to 360° it is East of North

Lat. / LHA	10°	20°	26°	30°	32°	34°	36°	38°	Lat. / LHA
	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	
0	0 00.0	0 00.0	0 00.0	0 00.0	0 00.0	0 00.0	0 00.0	0 00.0	360
5	0 04.8	0 05.1	0 05.3	0 05.5	0 05.6	0 05.8	0 05.9	0 06.1	355
10	0 09.6	0 10.1	0 10.6	0 11.0	0 11.2	0 11.5	0 11.8	0 12.1	350
15	0 14.3	0 15.0	0 15.8	0 16.4	0 16.7	0 17.1	0 17.6	0 18.1	345
20	0 18.9	0 19.9	0 20.8	0 21.6	0 22.1	0 22.6	0 23.2	0 23.9	340
25	0 23.4	0 24.6	0 25.7	0 26.7	0 27.3	0 28.0	0 28.7	0 29.5	335
30	0 27.7	0 29.1	0 30.4	0 31.6	0 32.3	0 33.1	0 33.9	0 34.8	330
35	0 31.7	0 33.3	0 34.9	0 36.3	0 37.0	0 37.9	0 38.9	0 40.0	325
40	0 35.5	0 37.3	0 39.1	0 40.6	0 41.5	0 42.5	0 43.6	0 44.7	320
45	0 39.1	0 41.1	0 43.0	0 44.7	0 45.6	0 46.7	0 47.9	0 49.2	315
50	0 42.3	0 44.5	0 46.5	0 48.3	0 49.4	0 50.6	0 51.8	0 53.2	310
55	0 45.3	0 47.5	0 49.7	0 51.7	0 52.8	0 54.0	0 55.4	0 56.9	305
60	0 47.8	0 50.2	0 52.6	0 54.6	0 55.8	0 57.1	0 58.5	1 00.1	300
65	0 50.1	0 52.5	0 55.0	0 57.1	0 58.3	0 59.7	1 01.2	1 02.8	295
70	0 51.9	0 54.4	0 57.0	0 59.1	1 00.4	1 01.8	1 03.4	1 05.1	290
75	0 53.3	0 55.9	0 58.5	1 00.7	1 02.0	1 03.5	1 05.1	1 06.8	285
80	0 54.4	0 57.0	0 59.6	1 01.9	1 03.2	1 04.7	1 06.3	1 08.0	280
85	0 55.0	0 57.6	1 00.3	1 02.5	1 03.9	1 05.3	1 07.0	1 08.8	275
90	0 55.2	0 57.8	1 00.5	1 02.7	1 04.1	1 05.5	1 07.2	1 08.9	270
95	0 54.9	0 57.6	1 00.2	1 02.4	1 03.8	1 05.2	1 06.8	1 08.6	265
100	0 54.3	0 56.9	0 59.5	1 01.7	1 03.0	1 04.4	1 06.0	1 07.8	260
105	0 53.3	0 55.8	0 58.3	1 00.5	1 01.7	1 03.1	1 04.7	1 06.4	255
110	0 51.8	0 54.2	0 56.7	0 58.8	1 00.0	1 01.4	1 02.9	1 04.5	250
115	0 49.9	0 52.3	0 54.6	0 56.6	0 57.8	0 59.1	1 00.6	1 02.2	245
120	0 47.7	0 49.9	0 52.2	0 54.1	0 55.2	0 56.5	0 57.8	0 59.3	240
125	0 45.1	0 47.2	0 49.3	0 51.1	0 52.2	0 53.4	0 54.7	0 56.1	235
130	0 42.2	0 44.1	0 46.1	0 47.8	0 48.8	0 49.9	0 51.1	0 52.4	230
135	0 38.9	0 40.7	0 42.5	0 44.1	0 45.0	0 46.0	0 47.1	0 48.3	225
140	0 35.4	0 37.0	0 38.6	0 40.0	0 40.9	0 41.8	0 42.8	0 43.9	220
145	0 31.6	0 33.0	0 34.5	0 35.7	0 36.5	0 37.3	0 38.2	0 39.2	215
150	0 27.5	0 28.8	0 30.0	0 31.1	0 31.8	0 32.5	0 33.3	0 34.1	210
155	0 23.3	0 24.3	0 25.4	0 26.3	0 26.8	0 27.4	0 28.1	0 28.8	205
160	0 18.8	0 19.7	0 20.5	0 21.3	0 21.7	0 22.2	0 22.7	0 23.3	200
165	0 14.2	0 14.9	0 15.5	0 16.1	0 16.4	0 16.8	0 17.2	0 17.6	195
170	0 09.6	0 10.0	0 10.4	0 10.8	0 11.0	0 11.3	0 11.5	0 11.8	190
175	0 04.8	0 05.0	0 05.2	0 05.4	0 05.5	0 05.7	0 05.8	0 05.9	185
180	0 00.0	0 00.0	0 00.0	0 00.0	0 00.0	0 00.0	0 00.0	0 00.0	180

Lat. / LHA	40°	42°	44°	46°	48°	50°	60°	70°	Lat. / LHA
	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	
0	0 00.0	0 00.0	0 00.0	0 00.0	0 00.0	0 00.0	0 00.0	0 00.0	360
5	0 06.3	0 06.5	0 06.7	0 06.9	0 07.2	0 07.5	0 09.7	0 14.5	355
10	0 12.5	0 12.9	0 13.3	0 13.8	0 14.3	0 15.0	0 19.4	0 28.8	350
15	0 18.6	0 19.2	0 19.8	0 20.6	0 21.4	0 22.3	0 28.9	0 42.9	345
20	0 24.6	0 25.3	0 26.2	0 27.2	0 28.2	0 29.4	0 38.1	0 56.6	340

Continued on next page

Lat.	40°	42°	44°	46°	48°	50°	60°	70°	Lat.
LHA									LHA
	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	
25	0 30.3	0 31.3	0 32.4	0 33.6	0 34.9	0 36.3	0 47.1	1 09.9	335
30	0 35.9	0 37.0	0 38.3	0 39.7	0 41.2	0 43.0	0 55.7	1 22.5	330
35	0 41.1	0 42.4	0 43.9	0 45.5	0 47.3	0 49.2	1 03.8	1 34.5	325
40	0 46.1	0 47.5	0 49.1	0 50.9	0 52.9	0 55.1	1 11.3	1 45.6	320
45	0 50.6	0 52.2	0 54.0	0 56.0	0 58.1	1 00.6	1 18.3	1 55.9	315
50	0 54.8	0 56.5	0 58.4	1 00.6	1 02.9	1 05.5	1 24.7	2 05.1	310
55	0 58.5	1 00.4	1 02.4	1 04.7	1 07.2	1 10.0	1 30.4	2 13.4	305
60	1 01.8	1 03.8	1 05.9	1 08.3	1 10.9	1 13.9	1 35.4	2 20.6	300
65	1 04.6	1 06.7	1 08.9	1 11.4	1 14.1	1 17.2	1 39.6	2 26.6	295
70	1 07.0	1 09.0	1 11.3	1 13.9	1 16.8	1 19.9	1 43.1	2 31.4	290
75	1 08.7	1 10.9	1 13.2	1 15.9	1 18.8	1 22.0	1 45.7	2 35.1	285
80	1 10.0	1 12.2	1 14.6	1 17.2	1 20.2	1 23.5	1 47.5	2 37.5	280
85	1 10.7	1 12.9	1 15.3	1 18.0	1 21.0	1 24.3	1 48.5	2 38.8	275
90	1 10.9	1 13.1	1 15.5	1 18.2	1 21.2	1 24.5	1 48.6	2 38.8	270
95	1 10.6	1 12.7	1 15.1	1 17.8	1 20.8	1 24.1	1 48.0	2 37.6	265
100	1 09.7	1 11.8	1 14.2	1 16.8	1 19.7	1 23.0	1 46.5	2 35.2	260
105	1 08.3	1 10.4	1 12.7	1 15.2	1 18.1	1 21.2	1 44.2	2 31.7	255
110	1 06.3	1 08.4	1 10.6	1 13.1	1 15.8	1 18.9	1 41.1	2 27.0	250
115	1 03.9	1 05.9	1 08.0	1 10.4	1 13.0	1 16.0	1 37.3	2 21.3	245
120	1 01.0	1 02.9	1 04.9	1 07.2	1 09.7	1 12.5	1 32.8	2 14.6	240
125	0 57.7	0 59.4	1 01.3	1 03.5	1 05.8	1 08.5	1 27.6	2 06.9	235
130	0 53.9	0 55.5	0 57.3	0 59.3	1 01.5	1 04.0	1 21.8	1 58.4	230
135	0 49.7	0 51.2	0 52.8	0 54.7	0 56.7	0 59.0	1 15.4	1 49.0	225
140	0 45.1	0 46.5	0 48.0	0 49.7	0 51.5	0 53.6	1 08.4	1 38.8	220
145	0 40.2	0 41.5	0 42.8	0 44.3	0 45.9	0 47.7	1 01.0	1 28.0	215
150	0 35.1	0 36.1	0 37.3	0 38.6	0 40.0	0 41.6	0 53.1	1 16.5	210
155	0 29.6	0 30.5	0 31.5	0 32.6	0 33.8	0 35.1	0 44.8	1 04.6	205
160	0 24.0	0 24.7	0 25.5	0 26.3	0 27.3	0 28.4	0 36.2	0 52.2	200
165	0 18.1	0 18.7	0 19.3	0 19.9	0 20.7	0 21.5	0 27.4	0 39.5	195
170	0 12.2	0 12.5	0 12.9	0 13.4	0 13.9	0 14.4	0 18.4	0 26.5	190
175	0 06.1	0 06.3	0 06.5	0 06.7	0 07.0	0 07.2	0 09.2	0 13.3	185
180	0 00.0	0 00.0	0 00.0	0 00.0	0 00.0	0 00.0	0 00.0	0 00.0	180

Table 10 has been computed for a polar distance of 0° 54.33′

TABLE 11
CORRECTION TO BEARING OF POLARIS FOR OTHER POLAR DISTANCES, 1963

Bearing	0°	20′	40′	1°	1°20′	1°40′	2°	2°20′	2°40′
Polar Dist.									
° ′	′	′	′	′	′	′	′	′	′
0 54.73	0.0	+0.1	+0.3	+0.4	+0.6	+0.7	+0.9	+1.0	+1.2
0 54.63	0.0	+0.1	+0.2	+0.3	+0.4	+0.6	+0.7	+0.8	+0.9
0 54.53	0.0	+0.1	+0.1	+0.2	+0.3	+0.4	+0.4	+0.5	+0.6
0 54.43	0.0	0.0	+0.1	+0.1	+0.1	+0.2	+0.2	+0.3	+0.3
0 54.33	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0 54.23	0.0	−0.0	−0.1	−0.1	−0.1	−0.2	−0.2	−0.3	−0.3
0 54.13	0.0	−0.1	−0.1	−0.2	−0.3	−0.4	−0.4	−0.5	−0.6
0 54.03	0.0	−0.1	−0.2	−0.3	−0.4	−0.6	−0.7	−0.8	−0.9
0 53.93	0.0	−0.1	−0.3	−0.4	−0.6	−0.7	−0.9	−1.0	−1.2

Note: This table has been recomputed, July 1962, and is believed to have more nearly correct values than those used in the past. The discrepancies in corrections between the values in this table and those in the tables used in the past do not exceed 0.1 minutes of arc and are the result of a gradual long term change in the declination of Polaris.

TABLE 12

GHA ♈ 1963

For 0^h Universal Time or Greenwich Civil Time

	Jan.	Feb.	Mar.	Apr.	May	June
	° ′	° ′	° ′	° ′	° ′	° ′
1	99 55.5	130 28.8	158 04.7	188 38.0	218 12.2	248 45.5
2	100 54.7	131 28.0	159 03.9	189 37.1	219 11.3	249 44.6
3	101 53.8	132 27.1	160 03.0	190 36.3	220 10.4	250 43.7
4	102 52.9	133 26.3	161 02.1	191 35.4	221 09.6	251 42.9
5	103 52.1	134 25.4	162 01.3	192 34.6	222 08.7	252 42.0
6	104 51.2	135 24.5	163 00.4	193 33.7	223 07.8	253 41.1
7	105 50.4	136 23.7	163 59.6	194 32.8	224 07.0	254 40.3
8	106 49.5	137 22.8	164 58.7	195 32.0	225 06.1	255 39.4
9	107 48.6	138 22.0	165 57.8	196 31.1	226 05.3	256 38.6
10	108 47.8	139 21.1	166 57.0	197 30.2	227 04.4	257 37.7
11	109 46.9	140 20.2	167 56.1	198 29.4	228 03.5	258 36.9
12	110 46.1	141 19.4	168 55.2	199 28.5	229 02.7	259 36.0
13	111 45.2	142 18.5	169 54.4	200 27.7	230 01.8	260 35.1
14	112 44.3	143 17.6	170 53.5	201 26.8	231 01.0	261 34.3
15	113 43.5	144 16.8	171 52.7	202 25.9	232 00.1	262 33.4
16	114 42.6	145 15.9	172 51.8	203 25.1	232 59.2	263 32.5
17	115 41.8	146 15.1	173 50.9	204 24.2	233 58.4	264 31.7
18	116 40.9	147 14.2	174 50.1	205 23.4	234 57.5	265 30.8
19	117 40.0	148 13.3	175 49.2	206 22.5	235 56.6	266 30.0
20	118 39.2	149 12.5	176 48.3	207 21.6	236 55.8	267 29.1
21	119 38.3	150 11.6	177 47.5	208 20.8	237 54.9	268 28.2
22	120 37.4	151 10.8	178 46.6	209 19.9	238 54.1	269 27.4
23	121 36.6	152 09.9	179 45.8	210 19.0	239 53.2	270 26.5
24	122 35.7	153 09.0	180 44.9	211 18.2	240 52.3	271 25.7
25	123 34.9	154 08.2	181 44.0	212 17.3	241 51.5	272 24.8
26	124 34.0	155 07.3	182 43.2	213 16.5	242 50.6	273 23.9
27	125 33.2	156 06.4	183 42.3	214 15.6	243 49.8	274 23.1
28	126 32.3	157 05.6	184 41.4	215 14.7	244 48.9	275 22.2
29	127 31.4	158 04.7	185 40.6	216 13.9	245 48.0	276 21.4
30	128 30.6		186 39.7	217 13.0	246 47.2	277 20.5
31	129 29.7		187 38.9	218 12.2	247 46.3	278 19.6
32	130 28.8		188 38.0		248 45.5	

TABLE 12—(Continued)

	July	Aug.	Sept.	Oct.	Nov.	Dec.
	° ′	° ′	° ′	° ′	° ′	° ′
1	278 19.6	308 53.0	339 26.3	9 00.4	39 33.7	69 07.8
2	279 18.8	309 52.1	340 25.4	9 59.5	40 32.8	70 07.0
3	280 17.9	310 51.2	341 24.5	10 58.7	41 32.0	71 06.1
4	281 17.1	311 50.4	342 23.7	11 57.8	42 31.1	72 05.3
5	282 16.2	312 49.5	343 22.8	12 56.9	43 30.2	73 04.4
6	283 15.3	313 48.6	344 21.9	13 56.1	44 29.4	74 03.6
7	284 14.5	314 47.8	345 21.1	14 55.2	45 28.5	75 02.7
8	285 13.6	315 46.9	346 20.2	15 54.4	46 27.7	76 01.8
9	286 12.8	316 46.1	347 19.4	16 53.5	47 26.8	77 01.0
10	287 11.9	317 45.2	348 18.5	17 52.6	48 25.9	78 00.1
11	288 11.0	318 44.3	349 17.6	18 51.8	49 25.1	78 59.2
12	289 10.2	319 43.5	350 16.8	19 50.9	50 24.2	79 58.4
13	290 09.3	320 42.6	351 15.9	20 50.1	51 23.3	80 57.5
14	291 08.4	321 41.8	352 15.0	21 49.2	52 22.5	81 56.7
15	292 07.6	322 40.9	353 14.2	22 48.3	53 21.6	82 55.8
16	293 06.7	323 40.0	354 13.3	23 47.5	54 20.8	83 54.9
17	294 05.9	324 39.2	355 12.5	24 46.6	55 19.9	84 54.1
18	295 05.0	325 38.3	356 11.6	25 45.7	56 19.0	85 53.2
19	296 04.1	326 37.5	357 10.7	26 44.9	57 18.2	86 52.4
20	297 03.3	327 36.6	358 09.9	27 44.0	58 17.3	87 51.5
21	298 02.4	328 35.7	359 09.0	28 43.2	59 16.5	88 50.6
22	299 01.6	329 34.9	0 08.1	29 42.3	60 15.6	89 49.8
23	300 00.7	330 34.0	1 07.3	30 41.4	61 14.7	90 48.9
24	300 59.8	331 33.1	2 06.4	31 40.6	62 13.9	91 48.1
25	301 59.0	332 32.3	3 05.6	32 39.7	63 13.0	92 47.2
26	302 58.1	333 31.4	4 04.7	33 38.9	64 12.2	93 46.3
27	303 57.3	334 30.6	5 03.8	34 38.0	65 11.3	94 45.5
28	304 56.4	335 29.7	6 03.0	35 37.1	66 10.4	95 44.6
29	305 55.5	336 28.8	7 02.1	36 36.3	67 09.6	96 43.8
30	306 54.7	337 28.0	8 01.3	37 35.4	68 08.7	97 42.9
31	307 53.8	338 27.1	9 00.4	38 34.5	69 07.8	98 42.0
32	308 53.0	339 26.3		39 33.7		99 41.2

TABLE 13

SIDEREAL HOUR ANGLE* AND DECLINATION* OF 26 SELECTED STARS, 1963

Corrected for First Day of Month Named

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
Achernar													
SHA 335° 55′	+.1	+.3	+.5	+.6	+.6	+.4	+.1	−.3	−.6	−.8	−.9	−.8	−.6
Decl. S57° 25′	+.9	+.9	+.8	+.6	+.4	+.3	+.1	+.1	+.1	+.2	+.3	+.5	+.6
Acrux													
SHA 173° 51′	+1.1	+.7	+.4	+.3	+.4	+.5	+.8	1.1	1.3	1.3	1.2	+.8	+.4
Decl. S62° 53′	+.3	+.4	+.5	+.7	+.9	1.0	1.0	1.0	+.8	+.7	+.6	+.5	+.6
Aldebaran													
SHA 291° 33′	0	+.1	+.2	+.3	+.4	+.4	+.2	0	−.2	−.4	−.6	−.7	−.8
Decl. N16° 26′	+.1	+.1	+.1	+.1	+.1	+.1	+.1	+.2	+.2	+.2	+.3	+.3	+.2
Alphard													
SHA 218° 33′	+.4	+.3	+.2	+.3	+.4	+.5	+.6	+.6	+.5	+.4	+.2	−.1	−.3
Decl. S 8° 29′	+.8	+.9	1.0	1.0	1.0	1.0	+.9	+.9	+.8	+.8	+.8	+.9	1.0
Alpheratz													
SHA 358° 22′	+1.2	1.3	1.3	1.3	1.2	1.0	+.7	+.5	+.3	+.3	+.3	+.4	+.5
Decl. N28° 53′	+.2	+.2	+.1	0	0	0	+.1	+.2	+.3	+.4	+.5	+.5	+.5
Altair													
SHA 62° 45′	+.9	+.8	+.7	+.5	+.2	0	−.1	−.2	−.2	0	+.1	+.2	+.2
Decl. N 8° 46′	+.2	+.1	0	0	+.1	+.1	+.3	+.3	+.4	+.4	+.4	+.4	+.3
Antares													
SHA 113° 12′	+1.5	1.3	1.1	+.8	+.6	+.5	+.5	+.5	+.7	+.8	+.9	+.8	+.7
Decl. S26° 21′	−.1	−.1	0	0	+.1	+.1	+.1	+.1	+.1	+.1	+.1	+.1	+.1
Arcturus													
SHA 146° 30′	+.8	+.5	+.3	+.2	+.1	+.1	+.2	+.3	+.4	+.4	+.4	+.3	+.1
Decl. N19° 22′	+.5	+.4	+.3	+.3	+.4	+.5	+.6	+.6	+.6	+.5	+.4	+.3	+.1
Canopus													
SHA 264° 12′	+.6	+.7	+.8	1.1	1.4	1.5	1.5	1.4	1.2	+.9	+.6	+.4	+.3
Decl. S52° 40′	+.6	+.8	+.8	+.9	+.8	+.7	+.5	+.4	+.2	+.2	+.2	+.4	+.6
Capella													
SHA 281° 30′	+.5	+.6	+.7	1.0	1.1	1.1	+.9	+.7	+.4	+.1	−.2	−.4	−.5
Decl. N45° 57′	+.7	+.8	+.8	+.8	+.7	+.7	+.6	+.6	+.6	+.6	+.7	+.7	+.8
Deneb													
SHA 49° 57′	+1.0	1.0	+.9	+.7	+.4	+.1	−.1	−.2	−.2	0	+.2	+.4	+.5
Decl. N45° 08′	+.9	+.8	+.7	+.6	+.6	+.7	+.8	1.0	1.1	1.2	1.3	1.2	1.1
Denebola													
SHA 183° 12′	+.6	+.4	+.2	+.2	+.2	+.3	+.4	+.4	+.5	+.4	+.3	+.1	−.2
Decl. N14° 46′	+.7	+.6	+.6	+.6	+.7	+.7	+.8	+.8	+.7	+.7	+.6	+.5	+.4
Diphda													
SHA 349° 33′	+1.2	1.3	1.4	1.4	1.3	1.1	+.9	+.7	+.5	+.4	+.4	+.4	+.5
Decl. S18° 11′	+.6	+.6	+.6	+.5	+.4	+.3	+.2	+.1	+.1	+.1	+.2	+.2	+.3

*All values including S Decl. are increased when the correction is plus, or decreased when the correction is minus. Thus Antares Decl. Jan. S 26° 20.9′; June S 26° 21.1′.

TABLE 13—(Continued)

SIDEREAL HOUR ANGLE* AND DECLINATION* OF 26 SELECTED STARS, 1963

Corrected for First Day of Month Named

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
Dubhe													
SHA 194° 38′	+.2	−.1	−.3	−.3	−.1	+.1	+.4	+.5	+.5	+.4	+.1	−.3	−.7
Decl. N61° 57′	−.1	−.1	0	+.1	+.3	+.3	+.3	+.2	0	−.1	−.3	−.4	−.4
Enif													
SHA 34° 24′	+.9	+.9	+.9	+.7	+.5	+.3	+.1	0	−.1	−.1	0	+.1	+.2
Decl. N 9° 42′	+.3	+.2	+.1	+.1	+.2	+.2	+.3	+.4	+.5	+.6	+.6	+.6	+.5
Fomalhaut													
SHA 16° 05′	+1.3	1.4	1.4	1.3	1.1	+.8	+.6	+.4	+.2	+.2	+.3	+.4	+.5
Decl. S29° 49′	+.4	+.3	+.3	+.2	+.1	0	−.1	−.1	−.1	−.1	0	+.1	+.1
Hamal													
SHA 328° 43′	+.8	+.9	1.0	1.1	1.1	+.9	+.7	+.5	+.2	+.1	0	0	0
Decl. N23° 17′	+.3	+.2	+.2	+.2	+.1	+.2	+.2	+.3	+.4	+.5	+.5	+.6	+.6
Menkent													
SHA 148° 52′	+.9	+.6	+.4	+.2	+.1	+.1	+.2	+.3	+.4	+.5	+.5	+.4	+.1
Decl. S36° 11′	0	+.1	+.2	+.3	+.4	+.5	+.5	+.5	+.5	+.4	+.3	+.3	+.3
Nunki													
SHA 76° 45′	+1.1	1.0	+.8	+.5	+.3	+.1	−.1	−.2	−.1	0	+.2	+.2	+.2
Decl. S26° 20′	+.6	+.6	+.6	+.6	+.6	+.5	+.5	+.6	+.6	+.6	+.6	+.6	+.6
Peacock													
SHA 54° 19′	+1.0	+.9	+.7	+.4	0	−.4	−.7	−.9	−.9	−.7	−.4	−.2	−.2
Decl. S56° 51′	+.4	+.3	+.2	+.1	+.1	+.1	+.1	+.2	+.3	+.4	+.4	+.4	+.3
Pollux													
SHA 244° 14′	+.1	0	+.1	+.2	+.3	+.4	+.4	+.3	+.1	−.1	−.3	−.6	−.8
Decl. N28° 06′	+.9	+.9	1.0	1.0	1.0	1.0	1.0	1.0	+.9	+.9	+.9	+.8	+.8
Rasalhague													
SHA 96° 41′	+1.3	1.1	+.9	+.7	+.5	+.4	+.3	+.3	+.4	+.6	+.7	+.7	+.6
Decl. N12° 35′	+.2	+.1	0	0	0	+.1	+.2	+.3	+.3	+.3	+.3	+.2	+.1
Regulus													
SHA 208° 23′	+1.0	+.8	+.7	+.8	+.9	1.0	1.0	1.0	1.0	+.9	+.7	+.5	+.2
Decl. N12° 08′	+.9	+.9	+.8	+.9	+.9	+.9	+.9	1.0	+.9	+.9	+.8	+.7	+.6
Sirius													
SHA 259° 07′	+.1	+.1	+.2	+.3	+.5	+.5	+.5	+.4	+.2	0	−.2	−.4	−.5
Decl. S16° 40′	0	+.1	+.1	+.1	+.1	0	−.1	−.2	−.3	−.3	−.2	−.1	0
Spica													
SHA 159° 11′	+.7	+.4	+.2	+.1	+.1	+.1	+.2	+.3	+.3	+.4	+.3	+.2	−.1
Decl. S10° 58′	0	+.1	+.1	+.2	+.2	+.2	+.2	+.2	+.1	+.1	+.1	+.2	+.3
Vega													
SHA 81° 04′	+1.3	1.2	1.0	+.7	+.5	+.3	+.2	+.2	+.3	+.5	+.7	+.8	+.8
Decl. N38° 45′	−.1	−.2	−.3	−.3	−.3	−.2	0	+.1	+.2	+.3	+.2	+.1	0

*All values including S Decl. are increased when the correction is plus, or decreased when the correction is minus. Thus Antares Decl. Jan. S 26° 20.9′; June S 26° 21.1′.

1963

	S	M	T	W	T	F	S		S	M	T	W	T	F	S
Jan.	..	..	1	2	3	4	5	July	..	1	2	3	4	5	6
	6	7	8	9	10	11	12		7	8	9	10	11	12	13
	13	14	15	16	17	18	19		14	15	16	17	18	19	20
	20	21	22	23	24	25	26		21	22	23	24	25	26	27
	27	28	29	30	31	..	..		28	29	30	31	..	..	..
	..	..	..	..	..	..	..		..	..	..	..	..	..	..
Feb.	..	..	..	..	..	1	2	Aug.	..	..	..	..	1	2	3
	3	4	5	6	7	8	9		4	5	6	7	8	9	10
	10	11	12	13	14	15	16		11	12	13	14	15	16	17
	17	18	19	20	21	22	23		18	19	20	21	22	23	24
	24	25	26	27	28	..	..		25	26	27	28	29	30	31
March	..	..	..	..	..	1	2	Sept.	..	..	..	..	..	..	..
	3	4	5	6	7	8	9		1	2	3	4	5	6	7
	10	11	12	13	14	15	16		8	9	10	11	12	13	14
	17	18	19	20	21	22	23		15	16	17	18	19	20	21
	24	25	26	27	28	29	30		22	23	24	25	26	27	28
	31	..	..	..	..	..	..		29	30	..	..	..	..	..
April	..	1	2	3	4	5	6	Oct.	..	..	1	2	3	4	5
	7	8	9	10	11	12	13		6	7	8	9	10	11	12
	14	15	16	17	18	19	20		13	14	15	16	17	18	19
	21	22	23	24	25	26	27		20	21	22	23	24	25	26
	28	29	30	..	..	..	..		27	28	29	30	31	..	..
May	..	..	..	1	2	3	4	Nov.	..	..	..	..	..	1	2
	5	6	7	8	9	10	11		3	4	5	6	7	8	9
	12	13	14	15	16	17	18		10	11	12	13	14	15	16
	19	20	21	22	23	24	25		17	18	19	20	21	22	23
	26	27	28	29	30	31	..		24	25	26	27	28	29	30
June	..	..	..	..	..	..	1	Dec.	..	..	..	..	..	..	..
	2	3	4	5	6	7	8		1	2	3	4	5	6	7
	9	10	11	12	13	14	15		8	9	10	11	12	13	14
	16	17	18	19	20	21	22		15	16	17	18	19	20	21
	23	24	25	26	27	28	29		22	23	24	25	26	27	28
	30	..	..	..	..	..	..		29	30	31	..	..	..	..

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